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A PRELIMINARY OUTLINE OF THE BASIC RESEARCH PROGRAM

The Foundation for the Study of Cycles has just raised a sum of money for a Basic Research Program. Through February 15, 1960, the sum of $35,768 in cash has been received toward a three year goal of $60,000.

How can this money best be spent?

One man's answer is to be found in a memorandum prepared for the Board of Directors of the Foundation by its Executive Director, Edward R. Dewey. This memorandum is printed below.

It is hoped that every reader of the JOURNAL *will study this memorandum and will mail in to the Board of the Foundation at 680 West End Avenue, New York 25, New York, his approval, his disapproval, or his comments.*

Letters from contributors and from Scientific Members are particularly desired.

The Editor

To the Board of Directors
Foundation for the Study of Cycles

THE BASIC RESEARCH PROGRAM

You have decided that we are to spend two years in fact-finding, one year in writing a book to recapitulate all that we have discovered during the 21-year period through 1961.

As I see it, the main objective of the book should be the organization of fact. It would be splendid if such organization led us to *why*, but it would be a major achievement if we learned anything about the *how*. For instance, if it were to be found that a certain cycle varies with solar radiation, we could very well let someone else worry about whether or not solar radiation *caused* the observed behavior.

"Organization of fact" implies facts to organize. The acquisition of fact *worthy* of organization is, as I see it, the main problem.

The work of the last 19 years has been largely exploratory and *ex*tensive. This work has resulted in four important clues:

1. Certain cycle wave lengths seem to be well established in both natural and social phenomena.
2. Certain cycle wave lengths seem to be related to each other by simple arithmetic progression, regardless of the phenomena in which found.
3. Certain cycle wave lengths seem to be related to certain astronomical phenomena.
4. Certain cyclic behaviors seem to evidence latitudinal passage—that is, these cycles seem to crest later and later as they are found closer and closer to the equator.

The isolation of fact worthy of organization means running down the above clues. For example, are the wave lengths in natural and social science phenomena *really* identical? Are the various cycle lengths *really* related? Is the seeming correspondence of terrestrial wave lengths with those of various astronomical phenomena real or spurious? Is latitudinal passage a fact, and if so, is it universal?

Fact should be uncovered in such a way as to throw all possible light on cause, association, and/or interrelationship.

What are the possible causes of rhythmic cycles?

1. Chance. (The presumptive cause of any given cycle.)
2. Internal dynamics. (The number two presumptive cause of any given cycle.)
3. Solar radiation of one sort or another. (Probably the most popular conjecture.)
4. The planets (or groups of planets)

cutting postulated "lines of force" from outer space. (Inigo Jones' theory.)

5. The angular relationships between planets, or groups of planets. (These relationships are the apparent cause of some of the variations in radio propagation quality.)
6. Some combination of items 4 and 5.
7. Energy waves from outer space.
8. The structure of the Universe itself.
9. Other possibilities not yet suggested.

Even if cause lies beyond us, the mere interrelationship of cycle length, if substantiated, has the virtue of helping to organize our material. The confirmation of such interrelationships would be an important step toward understanding these behaviors.

In making our study, here are some thoughts we should keep in mind:

1. A rhythmic cycle, to be worthy of serious study, should have repeated enough times, with enough strength, and with enough regularity, so that it cannot easily be the result of chance, or of internal dynamic forces. Investigation should be largely limited to such cycles.
2. If the cause of any of the cycles lies in the sun, it might be related *either* to the single or to the double sunspot cycle (sunspots with alternate cycles reversed). Both possibilities should be investigated.
3. If the cause of any of the cycles lies in the cutting of basic structural "lines of force" by planets or groups of planets, we would expect to find cycle wave lengths corresponding to or related to the *sidereal* periods of the planets—that is, to the time it takes the planets to go once around the sun, relative to the stars.
4. If the cause of any of the cycles lies in interplanetary relationships, we would expect to find wave lengths corresponding to, or related to, the *synodic* periods of the planets—that is, to the time it takes the planets to return to the same relationship to each other.
5. If the cause of any of the cycles lies in the structure of the Universe itself, or in forces from outer space, we would expect that the cycle wave lengths might correspond to the wave lengths of variable stars.

It should be obvious that to relate wave lengths to astronomical phenomena, or even to each other, we need great accuracy. Suppose, for example, that we wish to know whether or not the so-called 17¾-year cycle, so prevalent in earthly affairs, has any astronomical counterpart. We find four closely corresponding astronomical wave lengths, as shown in Table 1 below. One such wave length is a unit fraction of the time it takes Pluto to go around the sun. One is three times a unit fraction of the synodic period of Uranus and Neptune. One is the period of the variable star Scorpius V 381. One is a simple double and triple progression multiple of 1/5 of the time it takes Venus to go around the sun. All these lengths are within 12 days of 17.75 years—the first crude approximation of the terrestrial cycle. When we measure the 17.75-year wave length in terrestrial affairs more exactly, we can see to which, *if any*, of these four astronomical wave lengths it corresponds.

Table 1

The So-Called 17¾-Year Terrestrial Cycle
and
Various Closely Related Astronomical Lengths

The table illustrates
the great accuracy required
before a correspondence of wave length
can be even postulated

17¾ years	6,483 days
1/14 sidereal period of Pluto	6,481 days
Three times 1/29 the synodic period Uranus and Neptune	6,476 days
Period of Scorpius V 381	6,475 days
One hundred forty-four (2 x 2 x 2 x 2 x 3 x 3) times 1/5 the sidereal period of Venus.	6,471 days

Having made these measurements, we may be able to reject several, or all, of these astronomical phenomena as associated. Identity of wave length does not, of itself, prove anything, but if wave lengths can be proved to be *different*, by even the smallest amount, we have evidence that the cycles are unrelated. This truism holds whether we are talking of possible relatedness of wave length or of possible identity of wave length.

With these thoughts in mind, what are some of the things we might try to find out during the next two years?

It seems to me that our emphasis should change from the extensive to the intensive; that we should start to investigate a few things well instead of many things superficially.

I think we should more or less limit ourselves to one family of cycles where the "family tree" has been pretty well filled out. A "family" is defined as a group of cycles whose wave lengths are related to each other by double and triple progression. That is, for each cycle in the family there should be four others, viz.: one twice as long, one three times as long, one one-half as long, one one-third as long, and so on indefinitely. Families have no particular theoretical justification. But they have been observed.

Then we should largely concentrate upon those cycles within the family that evidence enough repetition so that the length of the cycle can be determined with great accuracy. In this way we can discover (1) if there are family relationships and (2) if there are any astronomical or other wave length tie-ins.

With these thoughts in mind, I would suggest that we begin our research with the so-called 17¾-year complex. I have four reasons: (1) 18 out of 21 possible members of this family between 1/3 years and 160 years long have already been found (i.e., alleged); (2) several members of the family have each been found in a dozen or more separate phenomena; (3) one member of the family (the 17¾-year cycle itself) has been found in three different series of figures, each over 1,500 years long; (4) one of the shorter alleged family members (the 17.12-week cycle in stock prices) has enjoyed over 270 repetitions and can be measured, assuming that we can wash randoms out completely, within 1/200th of a day.

SPECIFIC PROJECTS

(Arranged by cycle length; not in the order of importance or in the order in which they are to be prosecuted.)

THE 160-YEAR CYCLE

The 17¾-Year Cycle x 3 x 3

1. Make the best possible approximation of the length, strength, timing, shape, and characteristics of the 160-year cycle in Pig Iron Prices.

THE 142-YEAR CYCLE

The 17¾-Year Cycle x 2 x 2 x 2

2. Make the best possible approximation of the length, strength, timing, shape, and characteristics of the 142-year cycle in the Index of International War Battles, 500 B.C. to date.

THE 54-YEAR CYCLE

The 17¾-Year Cycle x 3

3. Find the exact length, strength, timing, shape, and characteristics of the 54-year cycle in British Wheat Prices, A.D. 1260 to date.

4. Ditto for Arizona Tree Rings, 54 B.C. to date.

5. Make a study of the 54-year cycle, as such, to see its characteristics in:

Prices, U.S.A.
Prices, Germany
Prices, Great Britain
Coal consumption, France
Coal production, England
Lead production, England
Arizona tree rings
Number of textile workers, England
Wages of agricultural workers, England
Value of French rente
Value of English consols
Pig iron production, England
Copper Prices, U.S.A.
Cotton acreage, U.S.A.
Deposits in savings banks
Foreign trade (Imports and Exports)
Interest Rates, U.S.A.
Ship building, U.S.A.
Devaluation in England
British wheat prices
Railroad stock prices, U.S.A.

Study particularly the correspondence of calendar timing, evidences of latitudinal passage, concurrent irregularities, and evidences of astronomical tie-in, if any.

See if this cycle really is three times as long as the 17¾-year cycle.

THE 35½-YEAR CYCLE

The 17¾-Year Cycle x 2

6. Find the exact length, strength, timing, shape, and characteristics of the 35½-year cycle in the value of British Consols.

7. Ditto for earthquakes in China, A.D. 200 to date.

8. Ditto for wheat prices in Western Europe.

9. Ditto for width of tree rings in England.

10. Ditto for width of tree rings in Arizona.

11. Comparative study of the 35½-year cycle in:

Abundance of lynx in Canada
Frequency of aurora
Frequency of earthquakes in China
European Weather
Barometic pressure of Batavia
Manufacturing production, U.S.A.
Wheat prices in Western Europe
Immigration into U.S.A.
Plant and tree growth in England
Thickness and thinness of tree rings
  in England
Harvests in Europe
Value of English Consols

Study along the lines indicated for Project 5 above. See if this cycle really is twice as long as the 17¾-year cycle.

THE 17¾-YEAR CYCLE

12. Find the exact length, strength, timing, shape, and characteristics of the 17¾-year cycle in the Index of Civil War Battles and International War Battles, 500 B.C. to date.

13. Ditto for the Index of Civil War Battles separately.

14. Ditto for the Index of International War Battles séparately.

15. Ditto for Chinese earthquakes, A.D. 200

to date, or as nearly to date as figures can be obtained.

16. Ditto for tree rings in Arizona, 54 B.C. to date.

17. Check the accuracy of the length determination of the 17¾-year cycle in the variable star Scorpius V 381.

18. Scan several other long series of figures, such as flood stages of the River Nile, Lake Saki varve thicknesses, Bristle cone pine widths, etc., to see if this cycle is present. If so, determine exact length, strength, timing, shape, and characteristics in each instance.

19. Make a study of the 17¾-year cycle, as such to see its characteristics in:

Liabilities of commercial and industrial failures
Pig iron prices
Cotton prices
Montgomery Ward sales
Stock prices
Sunspots, alternate cycles reversed
War
Variable star Scorpius V 381
Tree rings in Arizona
Earthquakes
Other series

THE 8.88-YEAR CYCLE

(The 17¾-Year Cycle ÷ 2)

20. Find the exact length, strength, timing, shape, and characteristics of this cycle in pig iron prices.

21. Ditto for sunspots, 1749 to date.

22. Ditto for sunspots, alternate cycles reversed, 1749 to date.

23. Make a comparative study of this cycle in these three series of figures. Is the length of this cycle really one-half of 17¾ years?

THE 5.91- OR 5.92-YEAR CYCLE

(The 17¾-Year Cycle ÷ 3)

24. Determine the exact length, strength, timing, shape and characteristics of the 5.91-year cycle in cotton prices, 1731-2 to date.

25. Ditto for sunspots with alternate cycles reversed, 1749 to date.

26. Ditto for rail stock prices, 1831 to date.

27. Ditto for 300 years of British wheat prices.

28. Ditto for Dow Jones Industrials, 1897 to date, using *weekly* figures.

29. Comparative study of the 5.91-year cycle in:

Sunspots, alternate cycles reversed
Liabilities of business failures
Index of railroad stock prices
Combined index of stock prices
Cotton prices
Pig iron prices
Copper prices
European wheat prices
Barometric pressure in Batavia
Index of Industrial Stock Prices

Is the length of this cycle really 1/3 of 17¾ years?

And so on for:

THE 4.44-YEAR CYCLE

(The 17¾-Year Cycle ÷ 2 ÷ 2)

THE 2.96-YEAR CYCLE

(The 17¾-Year Cycle ÷ 2 ÷ 3)

THE 1.97-YEAR CYCLE

(The 17¾-Year Cycle ÷ 3 ÷ 3)

THE 1.48-YEAR CYCLE

(The 17¾-Year Cycle ÷ 3 ÷ 2 ÷ 2)

THE 1.11-YEAR CYCLE

(The 17¾-Year Cycle ÷ 2 ÷ 2 ÷ 2 ÷ 2)

THE .99-YEAR CYCLE

(The 17¾-Year Cycle ÷ 2 ÷ 3 ÷ 3)

THE .74-YEAR CYCLE

(The 17¾-Year Cycle ÷ 3 ÷ 2 ÷ 2 ÷ 2)

THE .66-YEAR CYCLE

(The 17¾-Year Cycle ÷ 3 ÷ 3 ÷ 3)

THE .49-YEAR CYCLE

(The 17¾-Year Cycle ÷ 3 ÷ 3 ÷ 2 ÷ 2)

THE .33-YEAR CYCLE

(The 17¾-Year Cycle ÷ 2 ÷ 3 ÷ 3 ÷ 3)

in the various places in which each of these cycles has been discovered.

Having determined the exact wave length of all members of this family where the number of repetitions enables us to make a worthwhile determination, we might scan a few additional long term series, such as the 4,000-year Bristle-cone pine tree ring widths, or the 4,200-year Lake Saki varve width figures, to see if any of the members of this family are present there also.

When we have gone as far as we can in these directions, we can then determine the next steps to take.

Respectfully submitted

Edward R. Dewey
Executive Director

SCATTERED REPORTS AND LATITUDINAL PASSAGE IN RABBIT AND RODENT CYCLES

BY LEONARD W. WING

That the number of the snowshoe rabbit in northern North America rises to peaks of abundance and declines again in a cycle of about 9.6 years has been established. The dominant cycle of the lynx abundance is 9.60 years (Wing, 1953). So far as known, the cycle in the lynx and snowshoe rabbit are the same. Hence, until we have reason to do otherwise, we may accept 9.60 years as the best measure of the snowshoe rabbit cycle.

Established also as a cycle is a lemming fluctuation of about four years. Using the longest record available, nearly continuous for outbreaks since 1823 and fragmentary to about 1578, I have measured this by time-chart technique as 3.862 years long with ideal or typical timing of 1957.134 for middle Norway (64° 30' North Latitude) (Wing, 1957a).

In all cycles wherein tested so far, epochs* occur progressively later equatorward. This characteristic behavior is known as *latitudinal passage*. If the snowshoe rabbit and lemming cycles are associated also with latitudinal passage behavior, equatorward timings of highs and lows or of strength and weakness with respect to these wave lengths should be progressively later. A few seemingly unrelated events in the same wave length testify to this already. I have previously discussed the unseen relationship of these seemingly unrelated phenomena (Wing, 1957b, 1958). Hence, testing for latitudinal passage in rabbit and small rodent fluctuations clearly is in order. But how to do so is a difficult matter.

This paper will attempt to test past periods of reported rabbit and rodent outbreaks or scarcity, as the case may be, in North America for relationships to the (1) 9.60-year wave length as determined for the lynx and showshoe rabbit in northern Canada and (2) the 3.862-year wave length as determined for the lemmings in Norway. (There is no comparable record in the New World to that of the lemmings of Scandinavia.) It will attempt further to test these past periods of outbreak or scarcity, as the case may be, for possible latitudinal passage, a behavior known to occur in many and perhaps in all cycle wave lengths.

Earlier studies were limited to long records. Previously, these had to be numerical records, such as of fur returns, temperature records, tree ring measurements, and similar data gathered year by year for a long time. But development of the *time chart,* an invention by Chapin Hoskins and one of the most important and useful tools of cycle anaylsis, has made possible the use of long adjectival records, such as of "lemming years" and "flight years" (Dewey, 1949; Wing, 1953; Davis, 1956). Unfortunately, however, even a time chart must have consistent records, more than scattered and isolated reports. Long records at any one place are decidedly scarce. How then can we use scattered, single, and isolated reports?

Reports of rodent outbreaks especially are scattered, single records. Many rabbit reports are equally scattered, isolated reports. But these do not necessarily represent isolated events themselves. A person may have happened upon the beginning, the middle, or the end of a period of high or low. So few people write of outbreaks in the more formal literature that the chances of outbreaks being reported consistently, outbreak after outbreak, are very low indeed for any one place. We need, therefore, some objective technique that can use these isolated, scattered, and single reports.

Phase charts were developed for study of latitudinal passage, a principle of cycle behavior that seems universal. These may serve for isolated reports. On the phase chart, one plots timing of epoch by latitude with respect to calendar time. Typical or ideal timing for any long adjectival record (such as reports of "lemming years") can be determined by time charts. It can be computed for long numerical records by periodic tables. If either latitudinal passage or continent-wide agreement of these epochs occurs, it can be detected by a phase chart and the phase table upon which the phase chart is based.

**Epoch* in this paper means either a "high" or a "low."

I believe that the phase chart and phase table are suitable also for handling scattered reports of outbreak or other indications of abundance, either of high or of low. Being able to do this, they provide us with a new, additional tool for cycle research. If periods of abundance or of outbreak in other rabbits, for example, whether jack rabbits or cottontails, are related to the 9.60-year wave in the snowshoe rabbit, a latitudinal (or continent-wide) relationship should be present.

Seton reported hares to be scarce in the Lake Aylmer country during his canoe trip to the Arctic Prairies in 1907 (Seton, 1928). He gives no other indications of numbers, just the report for the one visit, Seton not having been there before. Nor did he add anything from testimony of the Indians. He knew of the rabbit cycle, however, having himself been one of the first to point out the phenomenon. It seems obvious that he was in some way comparing the numbers of hares at Lake Aylmer in 1907 with rabbits in other places or in other years. His report would seem to indicate that 1907 was during a period of *low.* Can we relate this and similar reports to each other and to the 9.60-year cycle? This is a difficult question to answer, but I hope to show that there is a relationship.

If this report marks a low period at Lake Aylmer (about 64° North Latitude) that is related to the 9.60-cycle, successive multiples of the 9.60-year cycle should give the same relationship to any late occurrence of the 9.60-year cycle as in 1907. Four multiples of 9.60 years or 38.4 years brings this period "up to date" and gives a "current timing" of 1945.4. To this we must add a half year to post at midyear, the average position of the calendar year. (In this particular case, calendar reconciliation may not be needed; Seton may have been writing of summer rather than of the 1907 calendar year. But the point is not particularly important in this case, though it may be in others.) The current timing now becomes 1945.9 of the calendar, as well as 1955.5.

Until we know otherwise, we may consider "highs" and "lows" as one half cycle apart. Therefore, if we add 4.8 years or one half the cycle to the low timing of 1945.9, we will get 1950.7 as a current timing of "high" at 64° North, based upon the 1907 report of scarcity, presumably a period of low. This rendition of the timing should have the same relationship to the high of the cycle for current time as did the low for 1907, each being in multiples of 9.60 years. Any other rendition in multiples of 9.60 years should also have the same relationship to the 9.60-year cycle. Any reports of rabbit numbers, either highs or lows, should behave in the same manner when similarly treated. This technique perhaps assumes the presence of a generating force at 9.60-year intervals. If agreement beyond a random pattern develops, the assumption of a regularly recurring generating force would seem valid. Otherwise, how can we have association with something not existing?

Bearing in mind this possible relationship, I set out to gather a hundred or more reports of highs or lows for American rabbits, from as far north to as far south as available (Table 1). It is not possible always to determine whether or not a traveler to a remote region or even one in a familiar place means to indicate a period of abundance or scarcity. It may be that he means only that rabbits are plentiful. It may be that the reporter is only comparing the rabbits with some other place, stated or unstated, with which he himself is familiar. Donald B. Macmillan writes, September 1915, 45 miles below Etah: "The green grass at Nerky was fairly dotted with the white bodies of 29 Arctic Hare. Jot squatted on the shore, and, resting his elbows on his knees, killed 5 before they decided that he was dangerous" (Seton, 1928). Whether this marks a report of a period of abundance, its beginning, or its end, we cannot say. But because records from so far north (78° 20' North) are otherwise practically nonexistent, I have used this as though reporting a high. This may be right; it may be wrong.

Many other reports are no more clear about periods of abundance or scarcity. This is especially true of rodent reports mentioned later. The larger size of rabbits and the greater awareness of their population cycle no doubt play parts in the rather better rabbit records. Mice seem always present in some numbers, even at the low, so that one report may merely record the fact that mice occur more in some habitats than in others. Reports of mice damage in orchards, for example, sometimes reflect the loudest protests of orchardists more than the numbers of mice. Even lemming reports may reflect some of the differences in habitat, though the tendency of lemming years to occur, particularly in the Old World, is well known and doubtlessly thereby influences reports.

Latitudinal passage operates from polar to equatorial regions (presumably 90° from Pole to Equator). But snowshoe rabbits and Arctic lemmings occur only in the northern areas. Hence, one may use reports of their highs and lows only over a limited latitude. But might outbreaks of Arctic hares to the north and jack rabbits and cottontails farther equatorward be associated with the same 9.60-year cycle as in the snowshoe rabbit, even though cottontails particularly have less spectacular population changes? Might the outbreaks in mice of America be associated with the same 3.862-year cycle as in the lemmings of Scandinavia? Are the ups and downs of one region or locality such as in a granary or orchard independent of those of other places? Or are they related? It will appear further on in this paper that many, at least, are related.

By search of easily examined literature, I have found 159 reports for rabbits (Table 1) and 204 for rodents (Table 2) in North America.* In some cases a report may refer to the same high as does another report, and I have tried to sort out duplicates. A report of a high in a neighboring area, however, would be considered an additional one. Additionally, two species reported as high at the same time in the same place, such as of *Microtus* and *Peromyscus*, would count as two reports of high. I do not have reports enough from other parts of the world for suitable testing. But it would be of interest to do so.

RABBITS

The timing of high for the snowshoe rabbit cycle was set at 1952.5 and 60° North Latitude in an earlier paper (Wing, 1957b). A time chart measurement of a series that has earlier highs gives 1952.1 (see Table 1). It pinpoints more closely the place as the Hudson's Bay to James Bay region, which appears to mean about 55° North. I have, therefore, chosen to use 1952.1 at 55° North in place of the previous 1952.5 at 60° North as the reference timing for the snowshoe rabbit cycle. The slight difference in timing and latitude, however, makes no important change. Presumably the use of a few earlier highs may make it more representative, but this may not be so necessarily.

If the 159 timings (Table 1) of high or low rendered as current timing of "high" relate with each other, they should all cluster about a common, current timing. If not related, their rendition as current calendar time should be randomly distributed. If at random, the 159 timings have equal opportunity to fall anywhere within multiples of 9.60 years. The relative position within any one multiple always will be the same as that within any other multiple, differing from each other by the 9.60 years of the multiple itself. The respective timings based upon 1952.1 will be earlier by multiples of 9.60, which gives 1942.5, 1932.9, 1923.3, 1913.7, etc., as reference points multiple by multiple. Within any single multiple, therefore, all timings must necessarily be the same distance from the reference timing in terms of multiples as the original timing. Hence, they are all comparable with each other and the reference timing (1952.1).

The high that occurred on the Athabasca in 1913—14, for example, should be counted as at calendar 1914.0, the mean position of the years 1913—14 or of the winter 1913—14, irrespective of which is meant. As this is 0.3 years after the earlier reference multiple of 1913.7, it would also have the relationship of 0.3 years after reference timing of 1952.1 four multiples of 9.60 years later. The multiple of 9.60 years having been added alike to the occurrence and to the reference, this would place the current timing with respect to the Athabasca report of 1913—14 as at 1952.4

But for other latitudes than 55°, one has the choice of using the same reference (1952.1) or one based upon latitudinal passage. In actual tests, both will be used, the former to indicate whether or not latitudinal passage may be present, the latter to indicate relationships more closely to the 9.60-year cycle on a continental basis.

It appears that in all cycles, at least in all so far tested, epochs appear first in the high latitudes and pass equatorward, simultaneously in the Northern and Southern Hemispheres. This has been demonstrated for a wide variety of phenomena, including physical phenomena, such as of temperature and barometric pressure. It has been noted in the field by a number of naturalists working upon the snowshoe rabbit. But it is not a habit confined to snowshoe rabbits alone. It appears to be a universal behavior. Any one cyclic occurrence or region may not necessarily show the general behavior. Some highs may occur or at least be noted earlier in some directions other than north or south. For some time I have accepted the ratio of latitudinal passage for 90° (Pole to Equator) given by the formula, $90^\circ \text{ Passage} = \sqrt{\frac{1}{2}(\text{Wave Length})^2}$. This amounts to 0.7071 times the wave length. For a 9.60-year wave, the passage rate would equal 6.8 years from Pole to Equator. Ideally, peaks would occur later by about 27½ days or about four weeks for each degree of latitude equatorward. This delay would be rather hard to notice in the field. Unless regular and comparable counts were made, it would be difficult to detect this difference except with mass data and for areas separated by long distances, local variations of habitat as well as difficulties inherent in field work being what they are.

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*No particular emphasis need be placed upon the number or the choice of reports themselves. Many more can be obtained by a thorough search of the literature. But these should be as representative as a more complete compilation would give.

The reference timing of 1952.1 at 55° North will, therefore, give reference timing of 1950.4 at 78° North, 1951.2 at the Arctic Circle, 1952.9 at 45° North, 1953.6 at 35° North, and 1954.4 at 25° North. (Reference timings for testing any behavior with respect to this wave in the Southern Hemisphere would be the same. As the year of record is the calendar year, roughly equivalent to the northern biological year, Southern Hemisphere timings would require some adjustment for any differences in year of record. The half year adjustment for the average position of the calendar (*i.e.*, midyear) would seem unnecessary, the biological year of the Southern Hemisphere including parts of two calendar years.)

I have constructed a phase chart, which is merely a grid with time placed horizontally and latitude placed vertically (Figure 1). Upon this grid I have placed the current timings of highs (fifth column of Table 1). I have also indicated, by a dashed line, passage for a 9.60-year wave with timing of 1952.1 at 55° North, presuming of course that passage occurs and that this line will indicate its probable course. I have also marked the boundaries of one half the wave length centered upon thus presumed passage line. The area bounded is thus from a quarter of a wave length before to a quarter of a wave length after passage.

If highs in rabbit numbers were wholly a matter of random behavior and, therefore, had no relationship one with the other, or with any other reference, the 159 timings reported in literature for the several species of rabbits would have equal opportunity to fall anywhere within multiples of 9.60 years. This would be particularly true of the earlier highs, which have been brought down to current timing in multiples of 9.60 years. One world-wide or one continent-wide event could conceivably influence any one single period of high. But if this happened also at 9.60-year intervals earlier, it would hardly be random anymore.

We can test randomness by Table 1 and Figure 1.

If at random, the rabbit highs all have the same opportunity to fall within one half of the wave length (4.80 years) as in the other half (4.80 years). At random, therefore, as many timings should fall in the half wave length centered about the passage line as in the other half. This marks the use of procedures of statistical analysis, which ordinarily is not particularly appropriate for use in cycle analysis. By simple counting, we shall find that those falling within the half wave length *centered* upon the passage line total 137 or 86% of the whole. Those falling within the half wave length *not centered* upon the passage line total 22 or 14% of the whole. The timings, in essence, prefer to fall within the half wave length centered upon the passage line by about 86% to 14% or 6.1:1. Thus, they were about six times more likely to fall within the centered half of the 9.60-year wave length than in the other half. I do not think it essential to show this further by application of complicated procedures of statistical analysis. It seems apparent enough already.

A large number of reports from a single, continent-wide period of high certainly could distort the pattern. This can be tested readily by comparing the behavior for periods, earlier ones and later ones. There are 82 reports after 1920 and 77 before. (Any other year could have been used; there is nothing particular about the years that I have used.) Of the 82, 71 fall within the centered half wave length and 11 fall outside. There are 35 for the period 1900 to 1919; of the 35, 30 fall within the centered half wave length and five fall outside it. There are 32 in the period 1860 to 1899. Of this number, 27 fall within the centered half of the wave length and five fall outside.

There are ten records more than a century earlier (before 1859). Of this number, nine fall within the centered half wave length and one falls outside. We may conclude that falling within or without the one-half wave length centered upon the passage line is wholly independent of the period in history when the high occurred. That being the case, it testifies to a generating influence that has occurred at intervals of 9.60 years in the past, at least as far as the record of rabbits goes.

The question arises naturally whether or not there is or is not latitudinal passage. With the scattered type of data now available, tests may still be run for latitudinal passage. If it does occur, the timings of more southerly highs should be later than the more northerly ones. The median timing of one region compared to that of the other should indicate suitably any difference.

For the purpose of this test, I have used a fixed calendar interval of 9.60 years, the same for all latitudes. The limits are set at 4.80 years before and 4.80 years after the reference timing of 1952.1 for Latitude 55° North. Any interval necessarily would have to center upon something, and the previously used reference point would seem to be the one to use. The limits of the interval of 9.60 years are, therefore, from 1947.3 to 1956.9.

The median of the 99 timings north of and including those at 50° Latitude is at 1951.9.

The median latitude of the reports between the extremes of 78° and 50° is at 55° Latitude; presumably this would be the latitude of the median timing (that is, the median timing at the median latitude). In a like manner, the median of the 60 timings south of and excluding 50° is at 1952.8. The median latitude of reports between the extremes of 50° and 29° 30' is at 44° Latitude; presumably this would be the latitude of the median timing at 1952.8 (that is, the median timing at the median latitude). The median of the more southerly highs thus falls 0.9 years later than the more northerly ones. As this represents the difference between the median latitudes of 55° and 44°, it indicates a passage of 0.9 years for 11° latitude. Using the formula 90° Passage = $\frac{1}{2}\sqrt{(\text{Wave length})^2}$, the theoretical passage for 11° is 0.83 years, rather close to that indicated by the medians.

If the timings for all latitudes were distributed at random, with no respect to latitudinal passage, those of more southerly distribution should have the same timing as the more northerly ones. In fact, with the 9.60-year interval having been centered upon 1952.1, both should at random have the timing of 1952.1. That the median of the more northerly timings falls at 1951.9 may not be particularly important; at random, it should have fallen at the centered position of 1952.1. But so also should the more southerly group of highs. This they do not do. In this respect, they agree with other phenomena.

It is possible to make a few other tests for comparing random and nonrandom behavior, bearing in mind that at random all highs have equal chance to fall anywhere within a space, any space, of 9.60 years. The highs as a whole fall within the centered half of the wave length by a measure of 137 to 22. Do the northern highs where the amplitude is presumably stronger in all cycles and the southern ones where the amplitude is presumably weaker behave alike? Or is the cycle tendency a matter only of the northern parts of the continent?

There are 99 highs from north of and including 50° Latitude. Of this number, 86 fall inside the half of the wave length centered upon the passage line and 13 fall outside for a ratio of 6.6 to one. There are 60 highs south of and excluding 50° Latitude. Of this number, 51 fall inside the half of the wave length centered upon the passage line while nine fall outside for a ratio of 5.7 to one. These data would seem to indicate that the behavior is not just one of the higher latitudes only. It occurs on the whole in both the northern and southern regions of the records.

The first half of one wave length (1947.3—1952.1) may be compared profitably with the second half (1952.1—1956.9). Fifty-two of the highs fall in the first half, three fall on the passage line, and 44 fall in the second half north of 50° inclusive. South of and excluding 50°, however, 21 highs fall in the first half and 37 in the second half, with two falling on the passage line. The groupings of the highs indicate clearly that the more southerly highs occur later than the more northerly ones, both the median timing and the distribution of the timings themselves.

The number of cottontail and jack rabbits is rather too few to show conclusively that their highs and lows separately fall more in the centered half of the wave length than in the other. There are, however, 12 cottontail reports. Of this number, 11 fall inside the centered half of the wave length and one falls outside. There are 16 jack rabbit reports. Of this number, 14 fall inside and two fall outside. The cottontail and jack rabbit reports are consistent in behavior with those of the snowshoe rabbits. If the small sample of each is at all representative, they would seem to follow the same 9.60-year cycle as the snowshoe rabbit farther North, timing varying only with latitude. A greater number of reports would presumably clarify this point.

SMALL RODENTS

The problems of testing rodent reports for both cycle timing and latitudinal passage are comparable in many ways to those of the rabbits. Yet no species of small rodent seems to have had the popular interest over so great a latitude as the snowshoe rabbit. Just as I have used "rabbits" of any and all species for which I could find readily available sample data, so also have I used "small rodents" of any and all species (Table 2). There may be several species involved in a single period of high at one location, which is seldom the case with rabbits.

In an earlier study (Wing, 1957a), I calibrated the lemming cycle as 3.862 years with an ideal or typical timing of high at 1957.134 in middle Norway (64° 30' North). This seems as close as practical with available data. I doubt that the cycle length is so precisely determined for the lemmings, however, as is the 9.60-year wave length, even though I give it in three decimals. The 9.60-year cycle appears to be within about 0.1% of correctness either way. Yet a value of 3.862 years seems entirely suitable for use here. Closer calibration would only improve the pattern of results; it would be unlikely to make material change.

The question arises naturally concerning the outbreaks of lemmings in America and their possible relationship to outbreaks of lemmings in the Old World. But perhaps one should ask first, for example, are outbreaks of mice in American orchards related to lemming years? Furthermore, can there be a relationship also to outbreaks of house mice, *Peromyscus,* and others? In a word, is there any commonality between outbreaks of house mice, white-footed mice, meadow mice, and other small rodents and the lemming cycle? One should hardly expect complete and perfect agreement, in any case. But do these things agree more than would be expected if by chance alone, just as in the several species of rabbits and hares? If the rodents of North America show the same cycle, might not those of Europe or of the whole world do also? This last cannot be answered here, but it is an intriguing possibility with some evidence in its support.

By a perusal of easily examined literature, I have found reports of 204 presumed highs (Table 2). Initially, I tried to grade the reports as *good, fair,* and *poor.* Thus, a long-time census would be rated *good.* But so few could be rated even *fair* that it was most discouraging, and I just had to drop the idea. A visitor in any area who reported that his camp was practically overrun with mice, for example, may have experienced a cyclic high, or its beginning or end. On the other hand, he may have camped in an area where mice are relatively abundant even during a population low. He may have just happened upon a local concentration that had no relationship to any cycle. Or he might have come from a mouse-free home and thereby been astonished by a few mice.

Be that as it may, there seems to be no objective way of evaluating the reports. Hence, I have given them the benefit of the doubt and treated each as a high (or low), unless the report indicated otherwise. Obviously, many of the reports will not be highs (or lows). But which are and which are not, cannot be told.

I prepared a phase chart (Figure 2) and entered a wave of 3.862 years with ideal timing of 1957.134 at 64° 30' North and limits of one-half wave length centered upon a passage line with this timing, passage line as of the formula: 90° Passage $= \frac{1}{2}\sqrt{(\text{Wave Length})^2}$. The passage would be about eleven days for each equatorward degree of latitude. For individual reports or even for long census reports in nearby regions, it would be rather difficult at best to detect this. But mass data and wider latitudinal distribution should indicate passage and also indicate if it occurs in American rodent outbreaks with respect to the lemming cycle (the latter based upon Scandinavian data).

Just as in the case of the 9.60-year phase chart for the rabbits (Figure 1), if the rodent outbreaks occur by chance, adding multiples of the 3.862-year wave length to the outbreak time (plus the usual one half year for adjusting to midyear of the calendar when a report is for a year) will give the same relationships for current time as for earlier time. Multiples of 3.862 years having been added alike to both the outbreak date and any reference date, relationships will remain as before. Hence, all reports will be comparable one with the other, in current time as in earlier, happening time. For reports of lows, I added a half cycle (1.931 years) to convert a report of a low to a "high", the high presumably being a half wave length from the low.

If the outbreaks are distributed at random, there would be no relationship between them save as several may reflect the same environmental influence for a particular epoch. No relationship could be expected to occur at random between reports of any one epoch and those of earlier years, especially when they represent not only different periods of time but distant places also.

If they do occur by chance, therefore, the 203 timings of Table 2 and Figure 2 have equal opportunity to fall anywhere within any space of 3.862 years. If they are perfectly related or perfectly reflect the 3.862-year lemming wave with timing and passage as indicated, they will fall exactly on its passage line. But perfection is more than anyone should expect. If the reports fall at random, however, the number falling within the half wave length centered upon the lemming timing and its passage should be the same as the number falling in the other half of the wave length. At random, the halves of the wave length will not differ. This we can test readily by simply counting the number within and outside the center half of the wave length. They are indicated in Column 5 of Table 2; their positions are also apparent in Figure 2.

Of the 204 reports rendered into current time by multiples of 3.862 years, 127 or 62% fall within the half wave length *centered* upon the lemming passage line, while 77 or 38% fall in the other half. This gives a ratio of 1.6 to one. Of the 16 timings determined by use of time charts, 14 fall inside and two fall outside the centered half of the wave length. In the rabbit chart, on the other hand, all the ten time-chart determinations fell within the centered half wave length.

That the ratio does not depend upon a single, continent-wide period of outbreak is attested by the earlier reports, few though they may be. Of the 155 after 1920, 99 fall within the centered half of the wave length and 56 fall outside. Of the 33 between 1900 and 1919, 17 fall within the centered half wave length and 16 fall outside. There are five between 1860 and 1899; three fall inside the centered half and two fall outside. Eight of the 11 more than a century earlier (before 1959) fall in the centered half of the wave length, while three do not. As might be expected, the earlier reports are scarce. Yet they remain consistent in showing the tendency to fall in the centered half of the wave length, just as in the rabbits. We may conclude that the highs of rodents, like those of rabbits, are not of random distribution. They are related in some way to the 3.862-year lemming wave identified in Norway.

We can test the rodent data in the same way as those of the rabbits to see if the more southerly data do or do not show later timing than the more northerly ones. The 3.862-year wave extends from 1.931 years before to 1.931 years after the reference year of 1957.134 or from 1955.203 to 1959.065, the same for all latitudes. (In the test, the passage line is not used, it being the thing under test.) The median timing of the 93 reports from and including 50° Latitude and northward falls at 1956.948. The median latitude of the reports between the extremes of 50° and 75° falls at 58° 50' North. Hence, the median timing of 1956.948 should be considered as representing the median latitude of 58° North.

In a like manner, the median timing for the 111 reports south of and excluding 50° North falls at 1957.560. The median latitude of the reports between the extremes of 30° 50' North and 50° North falls at 42° 17' North. Hence, we may consider the median timing is that of the median latitude of 42° 17'. The more southerly reports thus have a median timing that is 0.612 years later than that of the more northerly ones. The theoretical passage time for 16° 33' (between medians of 58° 50' North and 42° 17' North) is 0.502 years. As in the rabbit data of Figure 1, the actual passage shown by the highs falls rather surprisingly close to the theoretical value—about a month away.

The median timing of 1956.948 is also rather close to the lemming timing of 1957.134 at 64° 30' North from Scandinavia. Because I centered the 3.862-year wave length of reference at 1957.134, a perfectly random distribution should fall near the timing about which the 3.863-year interval is centered. But the median for the more southerly highs should also fall at the same timing. The fact that they do not and that they are consistent in behavior with those of the rabbits, equally objectively treated, attests, I think, to a reality.

Just as in the case of the rabbits, a further comparison of distribution of rodent highs with respect to the northern and southern latitudes reveals further the same nonrandom distribution. There are 93 highs north of and including 50° Latitude. Of this number, 52 fall within the half of the wave length centered upon the passage line, while 41 fall outside. There are 111 highs south of and excluding 50° Latitude. Of this number, 74 fall within the half wave length centered on the passage line and 37 fall outside.

The first half of one wave length (1955.203-1957.134) may be compared with the second half (1957.134—1959.065). North of and including 50° Latitude, 57 reports fall within the first half while 36 fall within the second half (61.3:38.7). South of and excluding 50° Latitude, however, 33 reports fall in the first half while 78 fall in the second (29.7:70.3). It appears that whether the medians or totals are used, the highs of the more southerly areas indicate later distribution. This later distribution equatorward marks the influence of the phenomenon of latitudinal passage.

The number of reports by species is rather too few for separate study other than for the lemmings and *Microtus*. There are 44 lemming reports; of this number, 32 fall inside the half wave length (1.931 years) centered about the Norwegian timing while 12 fall outside. Of the 68 *Microtus* reports, 41 fall inside the same half wave length while 27 fall outside. The next most numerous reports are the 17 for *Peromyscus*; seven fall inside and ten fall outside. Presumably reports given as "mice" or "small mammals" include *Microtus* as well as *Peromyscus*. There are 34 such reports;;21 fall inside the centered half wave length and 13 fall outside.

It would seem logical to conclude, therefore, that the cycle in Old World lemmings is present also in New World rodents. It would seem possible to conclude further that the timing of the two is the same and that in the New World, at least, latitudinal passage occurs. More southerly highs thus ideally occur later by 11 days for each degree of latitude. The ideal timing for any particular latitude may be computed by the formula currently established as: $90^\circ \text{ Passage} = \sqrt{\tfrac{1}{2}\,(\text{Wave Length})^2}$. The reference timing would be 1957.134 at 64° 30' North.

I do not have enough reports of small rodents in the Old World or Southern Hemisphere to undertake a study at this time. Those that I have assembled incidentally to the gathering of American reports so far agree with the findings from North America. If a larger number continue to show this trend, it would seem possible to conclude that in rodents, the world-wide pattern is the same as that of other widely distributed, cyclic phenomena.

The preceding indicates the presence of cyclic forces inducing rises and falls in the fortunes of animals—in this case rabbits and rodents, one with a cycle of 9.60-years and the other of 3.862 years. It should not be construed to mean that these are the only cyclic forces influencing these animals. While the cyclic forces quite evidently bear upon all latitudes, differences in rabbit and rodent numbers suggest differing responses in various environments. It is rather well known that even at their cyclic low, rabbits and rodents are more numerous in some habitats than in others. Never are they nonexistent at the low. The same can be said also for other cyclic animals, grouse for example.

It should be obvious that cyclic factors are but part of the influences upon birds and mammals. Neither the 9.60-year nor the 3.862-year wave are the only influences upon the lives of rabbits and rodents. What amount may be credited to them is not clear. At some times, however, a cycle influence would be seemingly all-important. But at others, it would appear neutralized or overwhelmed by other factors. Among these are the operations of other cycles. Yet noncyclic factors operate also. The resultant is obviously some sort of "compromise." Like all compromises, it probably reflects more of one thing one time and more of another thing another time.

SUMMARY

North American rabbit and hare reports of highs (or lows) totaling 159 have been rendered into current time with respect to the 9.60-year wave length. Reference timing for comparative purposes is established as 1952.1 at 55° North Latitude. The timings are not randomly distributed, having a ratio of about 6½ to one. Timings from different periods (before 1920, before 1900, before 1860) consistently show a similar nonrandom distribution. A majority of rabbit reports of abundance have been associated with occurrence of the 9.60 year cycle. The more southerly reports show later timings than more northerly ones, which thus indicates the presence of latitudinal passage. The rate shown by the rabbits very closely approaches the ideal or theoretical rate. Rabbit reports cover North American from 78° 20' North to 29° 30' North.

North American small rodent reports of highs (or lows) totaling 204 have been rendered as current timings with respect to the 3.862-year cycle as found in Scandinavian lemmings. Reference timing for comparative purposes is that of Norwegian lemmings: 1957.134 at 64° 30' North Latitude. The timings are not randomly distributed by a ratio of 1.6 to one. Timings from different periods (before 1920, before 1900, before 1860) consistently show a similar nonrandom distribution. A majority of past reports of rodent abundance have been associated with the occurrence of the 3.862-year cycle. The more southerly reports show later timings than the more northerly ones, which thus indicates probable latitudinal passage. The rate shown by the small rodents closely approaches the ideal or typical rate. Small rodent reports in North America cover the area from 75° North to 30° 50' North.

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TABLE 1. RABBIT HIGHS OR LOWS REPORTED IN NORTH AMERICA

SPECIES	PLACE	NORTH LATITUDE ° '	TIME OF REPORTED HIGH	CURRENT TIMING OF HIGH	SOURCE
Greenland Hare	Etah, Greenland	78 20	1915	1953.9**	Seton
" "	Oscar Land	78	1900-2	1949.5	"
Arctic Hare	Anderson River	68 30	1861*	1952.7	"
" "	Baffin Island	68	1922-3	1951.8	JM 17:315
" "	John R. Alaska	67	1946	1956.1**	Arctic 4:147-177
" "	Cockburn Land	66 30	1924	1953.3	JM 24:47-59
" "	Southhampton I.	66	1933-5	1953.7	"
" "	" "	66	1940	1950.1	"
" "	Seward Penn, Alaska	65 30	1947-8*	1952.8	JM 32:88-99
Snowshoe Rabbit	Mackenzie River	65	1903-4	1952.0	Seton
" "	Fairbanks, Alaska	64 44	1911-2	1950.4	JM 2:20-28
" "	Lake Aylmer	64	1907*	1950.7	Seton
" "	Mt. McKinley	63 20	1927*	1951.5	Fau Nat Pk 5
" "	" "	63 20	1925	1954.3**	Fau Nat Pk 3
" "	Hay River	61	1913	1951.9	JM 2:101-108
Arctic Hare	Artillery Lake	61	1913-4	1952.4	JM 13:19-36
Snowshoe Rabbit	Atlin Lake	60	1932-3	1952.2	JM 17:398-405
" "	Wood Buffalo Park	60	1922-3	1951.8	JM 23:119-145
" "	" " "	60	1932-3	1952.2	"
" "	Northern Canada	60	1845	1951.1	J. Cycle Res 6:55-119
" "	" "	60	1855	1951.5	"
" "	" "	60	1865	1951.9	"
" "	" "	60	1877	1954.3**	"
" "	" "	60	1887	1954.7**	"
" "	" "	60	1894	1952.1	"
" "	" "	60	1906	1954.5**	"
" "	" "	60	1912	1950.9	"
" "	" "	60	1923	1952.3	"
" "	" "	60	1941	1951.1	"
" "	" "	60	1952	1952.5	"
" "	" "	60	1850*	1951.3	"
" "	" "	60	1861*	1952.7	"
" "	" "	60	1871*	1953.1	"
" "	" "	60	1881*	1953.5	"
" "	" "	60	1889*	1951.9	"
" "	" "	60	1900*	1953.3	"
" "	" "	60	1908*	1951.7	"
" "	" "	60	1918*	1952.1	"
" "	" "	60	1930*	1954.5**	"
" "	" "	60	1937*	1951.9	"
" "	" "	60	1945*	1950.3	"
" "	" "	60		1952.5	(Time Chart)
" "	Northern Alberta	58	1912	1950.9	Seton
" "	Athabasca dnstream	57 30	1914	1952.9	JM 13:19-36
" "	British Columbia	56	1872	1949.3**	Seton
" "	" "	56	1923	1952.3	JWM 18:90-106
" "	" "	56	1932-3	1952.2	"
" "	" "	56	1938-9	1948.6**	"
" "	" "	56	1936-7*	1951.4	"
" "	" "	56	1944-5*	1949.8	"
" "	" "	56		1951.2	(Time Chart)
" "	Gr. Prairie, Alb.	55	1912-3	1952.6	JM 29:49-64
" "	Athabasca headwtrs	55	1885	1952.7	Seton
" "	Athabasca River	55	1913-4	1952.4	"
" "	Hudson-James Bay	55	1793	1956.7**	U. Toronto Stu 43
" "	" "	55	1799	1953.1	"
" "	" "	55	1808	1952.5	"
" "	" "	55	1815	1949.9	"
" "	" "	55	1856	1952.5	"
" "	" "	55	1864	1950.9	"
" "	" "	55	1875	1952.3	"
" "	" "	55	1886	1953.7	"
" "	" "	55	1895	1953.1	"
" "	" "	55	1904	1952.5	"
" "	" "	55	1914	1952.9	"
" "	" "	55	1923	1952.3	"
" "	" "	55	1933	1952.7	"
" "	" "	55		1952.1	(Time Chart)

TABLE 1. Continued

SPECIES	PLACE	NORTH LATITUDE ° '	TIME OF REPORTED HIGH	CURRENT TIMING OF HIGH	SOURCE
Snowshoe Rabbit	Labrador	55	1935*1937*	1950.9	JM 19:429-434
" "	Alberta	55	1922-3	1951.8	JWM 18:90-106
" "	"	55	1931-2	1951.2	"
" "	"	55	1940-1	1950.6	"
" "	"	55	1935-6*	1950.4	"
" "	"	55	1944-5*	1949.8	"
" "	"	55		1952.2	(Time Chart)
" "	"	55	1951	1951.5	JWM 18:52-60
" "	"	55	1945*	1950.3	"
" "	Saskatchewan	55	1922-3	1951.8	JWM 18:90-106
" "	"	55	1931-2	1951.2	"
" "	"	55	1938-9	1948.6**	"
" "	"	55	1934-5*	1949.4**	"
" "	"	55	1943-4*	1948.8**	"
" "	"	55		1951.2	(Time Chart)
" "	Manitoba	55	1922-3	1951.8	JWM 18:90-106
" "	"	55	1931-2	1951.2	"
" "	"	55	1940-1	1950.6	"
" "	"	55	1935-6*	1950.4	"
" "	"	55	1944-5*	1949.8	"
" "	"	55		1951.2	(Time Chart)
" "	Central Manitoba	54	1894	1952.1	Seton
Artic Hare Snowshoe Rabbit	Interior Labrador	54	1927-8*	1952.0	JM 11:1-10
Snowshoe Rabbit	Quebec	51 30	1932-3	1952.2	JWM 18:90-106
" "	"	51 30	1941-2	1951.6	"
" "	"	51 30	1936-7*	1951.4	"
" "	"	51 30	1946-7*	1951.8	"
" "	"	51 30		1952.1	(Time Chart)
" "	Pembina, Man.	50	1905-7	1954.0	JM 4:264-265
" "	Portage la Loche	50	1875	1952.3	Seton
" "	Reaburn, Man.	50	1884	1951.7	"
" "	School Lake, Man.	50	1883-4	1951.2	"
" "	" " "	50	1893-4	1951.6	"
" "	Southern Manitoba	50	1886-7	1954.2	"
" "	Portage la Prairie	50	1896	1954.1	"
" "	Eastern Manitoba	50	1904	1952.5	"
" "	British Columbia	50	1922	1951.3	Rept Prov Mus 1935
" "	" "	50	1933	1952.7	" "
" "	Lake-of-the-Woods	49 10	1856	1952.5	Seton
" "	" "	49 10	1934-5	1954.2	JM 17:216-221
" "	Upper Assinboine	49	1857	1953.5	Seton
" "	Newfoundland	48 30	1957-8*	1953.2	JWM 22:384-394
" "	Fort Williams	48 20	1858-9	1955.0	Seton
" "	Marshall Co. Minn.	48 15	1897 win.	1954.6	JM 11:434-452
" "	Cook Co. Minn	48	1929-30	1949.2**	JM 17:216-221
" "	" "	48	1911	1949.9**	"
" "	Minnesota	47	1933	1952.7	JM 18:46-57
" "	"	47	1923	1952.3	Leopold GS
Wh-T. Jack R.	Bismark, N.D.	46 49	Jan. 1924	1952.8	Seton
Snowshoe Rabbit	Cloquet, Minn.	46 45	1929	1948.7**	JWM 18:109-112
" "	" "	46 45	1935	1954.7	"
" "	" "	46 45	1943	1953.1	"
" "	" "	46 45	1950	1950.5	"
" "	" "	46 45		1954.1	(Time Chart)
" "	Sudbury, Ontario	46 32	1916	1954.9	Seton
Wh-T. Jack R.	Hettinger Co. N.D.	46 30	Dec. 1924	1953.7	NAF 49
Snowshoe Rabbit	Sherburne Co. Minn.	45 30	1905*	1948.7**	JM 10:153-164
Cottontail R.	" "	45 30	1915-7*	1950.1**	"
Snowshoe Rabbit	Door Co. Wisconsin	45	1927-8*	1952.0	JM 13:1-19
" "	Minn-Wisc	45	1923-5	1953.3	JWM 17:487-494
" "	"	45	1932-5	1953.2	"
" "	Yellowstone Park	44 45	1903	1951.5	Fau Nat Pks 4
" "	Trempeleau, Wisconsin	44 30	1876	1953.3	Leopold GS
" "	Jackson Co. Wisconsin	44 30	1880	1957.3**	"
Wh-T. Jack R.	Rapidan, Minn.	44 10	1918*	1952.1	NAF 49
" "	" "	44 10	1928*	1952.5	"
" "	" "	44 10	1933-4, 34-5	1953.7	"

TABLE 1. Continued

SPECIES	PLACE	NORTH LATITUDE ° ′	TIME OF REPORTED HIGH	CURRENT TIMING OF HIGH	SOURCE
Wh-T. Jack	Rapidan, Minn.	44 10	1922	1951.3	NAF 49
Snowshoe Rabbit	Wisconsin	44	1916	1954.9	Leopold GS
" "	"	44	1922	1951.3	"
" "	"	44	1919*	1953.1	"
" "	"	44	1927*	1951.5	"
" "	"	44		1953.3	(Time Chart)
Cottontail R.	"	44	1937*	1951.9	JM 24:18-22
Blk-T. Jack R.	Crook Co. Oregon	43 30	1916-7	1955.4	Seton
Jack Rabbit	Harney Co. Oregon	43	1915	1953.9	JM 5:165-173
Cottontail R.	Prairie du Sac	43 17	1940-1, 42-3	1951.1	Ecol Mon 7:
" "	Southern Wisconsin	43	1928-30*	1953.5	JM 19:110-111
" "	" "	42 45	1936-7	1951.4	"
" "	Ann Arbor, Mich.	42 17	1953.4	1954.0	(original)
Jack Rabbit	Nevada	41	1951-2	1952.0	JWM 19:225-233
Cottontail R.	Illinois & Indiana	41	1928-9*	1953.0	Leopold GS
" "	Pennsylvania	41	1936*	1950.9	JM 24:18-22
Blk-T. Jack R.	Utah	40 45	1946-7*	1951.8	JM 32:113-115
Cottontail R.	Logan Co. Ill.	40	1870-4*	1954.1	Leopold GS
Blk-T. Jack R.	Kansas	39	1952-6	1954.5	JWM 22:409-414
" "	Western Kansas	39	1934	1953.7	Kan Acad 38:351-352
Cottontail R.	Missouri	38 30	1950 fall	1950.8	JWM 23:34-39
" "	"	38 30	1929*	1953.5	Leopold GS
Blk-T. Jack R.	Lamar, Colorado	38 4	1894	1952.1	Seton
Snowshoe Rabbit	West Virginia	38	1932-3	1952.2	JWM 19:54-61
" "	" "	38	1941-2	1951.6	"
" "	" "	38	1952	1952.5	"
" "	" "	38	1936-7*	1951.4	"
" "	" "	38	1945-6*	1950.8**	"
" "	" "	38		1952.5	(Time Chart)
Cottontail R.	California	36	1938*	1952.9	JM 24:18-22
Blk-T. Jack R.	"	35	1910	1948.9**	Seton
" "	"	35	1915	1953.9	"
Cottontail R.	Oklahoma	35	1940* fall	1955.2	Okla Game Surv
Blk-T. Jack R.	Brewster Co. Texas	29 30	May 1947	1957.0**	JM 29:186-187

TABLE 2. SMALL RODENT HIGHS OR LOWS REPORTED IN NORTH AMERICA

SPECIES	PLACE	NORTH LATITUDE ° ′	TIME OF REPORTED HIGH	CURRENT TIMING OF HIGH	SOURCE
Lemming	Northern Baffin I.	75	1937	1956.810	JAE 19, Fig 25
"	" "	75	1941	1956.948	"
"	" "	75	1944	1956.086	"
"	" "	75		1956.948	(Time Chart)
"	Western Victoria I.	72	1938	1957.810	JAE 19, Fig 25
"	" "	72	1941	1956.948	"
"	" "	72	1946	1958.086**	"
"	" "	72		1956.948	(Time Chart)
"	Barrow, Alaska	71 15	May 1888	1957.886	Arctic 8:37-45
"	" "	71 15	1946	1958.086**	Trans NA WL Conf
"	" "	71 15	spr. 1949	1957.069	Arctic 4:147-177
"	" "	71 15	1953	1957.362	Ecol Mon 25:85-117
"	" "	71 15	1951*	1957.293	"
"	" "	71 15		1956.974	(Time Chart)
"	Perry River	70	May 1937	1956.680	Arctic 8:37;45
"	King William I.	69 10	1934	1957.672	"
"	Eastern Victoria I.	69	1937	1956.810	JAE 19:, Fig 25
"	" "	69	1942	1957.948	"
"	" "	69	1946	1958.086**	"
"	" "	69		1957.948	(Time Chart)
"	Baffin Island	66 30	July 1931*	1956.640	JM 25:221-254
"	" "	66 30	1938-9*	1956.379	"
"	Southern Baffin I.	65	1937	1956.810	JAE 19, Fig 25
"	" "	65	1941	1956.948	"
"	" "	65	1945	1957.086	"
"	" "	65		1956.948	(Time Chart)
"	Alaska-Yukon border	65	1918	1957.120	Arctic 8:37-45

TABLE 2. Continued

SPECIES	PLACE	NORTH LATITUDE ° '	TIME OF REPORTED HIGH	CURRENT TIMING OF HIGH	SOURCE
Lemming	C. Dorset, Baffin I.	64	1923*	1956.327	JM 25:221-254
"	" "	64	1926	1957.396	"
"	Southampton I.	64	1929-30	1957.034	Auk 48:501
Mice	Mt. McKinley Park	63 20	1939*	1956.879	Fau Nat Pks 5
Lemming	" "	63 20	1907	1957.706	Fau Nat Pks 3
M. drummondi	" "	63 20	1907	1957.706	"
"	" "	63 20	1926	1957.396	"
"	" "	63 20	1932*	1957.603	"
M. miurus	" "	63 20	1907	1957.706	"
"	" "	63 20	1926	1957.396	"
"	" "	63 20	1932*	1957.603	"
Evotomys	" "	63 20	1907	1957.706	"
Lemming	Lake Harbor	63	1930	1957.534	JM 25:221-254
"	" "	63	July 1931*	1956.640	"
"	" "	63	1938-9*	1956.379	"
"	Atlin-Lake Teslin	60	1923	1958.258**	JM 17:398-405
"	Northern Quebec	60	1937	1956.810	JAE 19, Fig 25
"	" "	60	1941	1956.948	"
"	" "	60	1943	1958.948**	"
"	" "	60	1947-8	1955.724**	"
"	" "	60		1956.336	(Time Chart)
"Small mammals"	Ft. Chimo, Ungava Bay	59	1946*	1956.155**	JM 30:309-311
" "	" "	59	1948	1956.224**	"
Lemming	Churchill	58 50	1929	1956.534	Auk 62:592-596
"	"	58 50	1933	1956.672	"
"	"	58 50	1936	1955.810**	"
"	"	58 50	1940	1955.948**	"
"	"	58 50	1943-4	1955.586**	"
"	"	58 50	1931*	1956.603	"
"	"	58 50	1934-5*	1956.241**	"
"	"	58 50	1938*	1955.879**	"
"	"	58 50	1942*	1956.017**	"
"	"	58 50		1956.310	(Time Chart)
Microtus	"	58 50	1937	1956.810	Ecol 24:742-484
Lemming	Northern Labrador	55	1938	1957.810	JAE 19, Fig 25
Peromyscus	Hudson-James Bay	55	1949	1957.224	JM 32:462
"	" "	55	1950*	1956.293**	"
M. pennsylvanicus	Gr. Prairie Man.	55	1944*	1958.017	JM 29:49-64
Microtus	Labrador	54	1832	1956.084**	Elton
"	"	54	1837-8	1957.722	"
"	"	54	1841	1957.360	"
"	"	54	1846	1958.498**	"
"	"	54	1853	1957.774	"
"	"	54	1874-5	1956.102**	"
"	"	54	1904-5	1955.206**	"
"	"	54	1908	1958.706**	"
"	"	54	1913	1955.982**	"
"	"	54	1916-7	1955.620**	"
"	"	54	1920	1959.120**	"
"	"	54	1924-5	1955.896**	"
"	"	54	1839*	1957.291	Elton
"	"	54	1903*	1955.637**	"
"	"	54	1906*	1958.637**	"
"	"	54	1910*	1958.775**	"
"	"	54		1956.654	(Time Chart)
Peromyscus	Interior Labrador	54	1927-8*	1956.965	JM 11:1-10
Mice	Northwest Labrador	54	1932-3	1956.172**	Elton
"	Labrador	54	1905	1955.706**	Conf Emp Meteor 1929:121-127
"	"	54	1906*	1958.637**	"
"	Kamloops, B. C.	50 40	Jan 1929	1956.075**	Elton
"	Woodlands, Man.	50 12	1894	1956.292**	"
"	" "	50 12	1900	1958.430	"
"	" "	50 12	1922-3	1957.758	"
"	" "	50 12	1927	1958.396	"
"	" "	50 12	1929	1956.534**	"
"	" "	50 12		1957.482	(Time Chart)
M. richardsoni	Avalanche Pass, B. C.	50	1924	1955.396**	Rpt Prov Mus 1935

TABLE 2. Continued

SPECIES	PLACE	NORTH LATITUDE ° '	TIME OF REPORTED HIGH	CURRENT TIMING OF HIGH	SOURCE
S. borealis	Avalanche Pass BC	50	1924	1955.396**	Rpt Porv Mus 1935
"	" "	50	1927*	1956.465**	"
C. gapperi	" "	50	1923	1958.258	"
M. mordax	" "	50	1924	1955.396**	"
P. maniculatus	" "	50	1924	1955.396**	"
"	" "	50	1925-6*	1958.827**	"
"	" "	50	1932	1955.672**	"
Mice	Saskatchewan	50	Jan 1929	1956.075**	Elton
M. pennsylvanicus	Winnipeg, Man.	49 47	1952	1956.362**	JM 38:87-97
"	" "	49 47	1955	1955.500**	"
C. gapperi	" "	49 47	1952	1956.362**	"
"	" "	49 47	1955	1955.500**	"
P. maniculatus	Fort Buford, N.D.	48 8	1887	1957.016	NAF 49
"	Badlands of N.D.	48	1913	1955.982**	"
Zapus	Snoqualmie Pass	47 30	1920	1959.120**	JM 4:149-155
C. gapperi	New Brunswick	47 30	1948	1956.224**	JM 36:21-35
"	" "	47 30	1951	1955.362**	"
Mice	Washington (state)	47	1922	1957.258	F&W Cons Bull 36
House Mouse	Fargo, N.D.	46 53	1912	1958.844**	NAF 49
Zapus	Mt. Ranier	46 50	1919	1958.120	JM 4:149-155
M. richardsoni	"	46 50	1918-9	1957.620	"
Mice	Pullman, Wash.	46 44	May 1957	1957.350	JM 40:455-457
"	Prince Edward I.	46 30	1775	1957.014	Elton
"	" "	46 50	1814-5	1957.894	"
"	Nova Scotia	46	1775	1957.014	"
"	" "	46	1814-5	1957.894	"
M. pennsylvanicus	Sherburne Co. Minn.	45 30	spr. 1924	1959.103**	JM 10:153-164
"	" "	45 30	1925*	1958.327	"
"	" "	45 30	fall 1926	1958.146	"
M. minor	" "	45 30	spr. 1927	1958.241	"
C. gapperi	Nova Scotia	45	1928	1959.396**	JM 17:207-215
"	" "	45	1933	1956.672**	"
Microtus	" "	45	1933*	1958.603	"
C. gapperi	" "	45	1927	1958.396	JM 11:318-320
"	" "	45	1928*	1957.465	"
"Small mammals"	Yellowstone Park	44 45	1919	1958.120	JM 4:149-155
" "	" "	44 45	1920*	1957.189	"
Microtus	" "	44 45	1937	1956.810	"
Neotoma	Jackson Hole, Wyo	43 55	1941	1956.948	JM 31:196-197
"	" "	43 55	1948-9*	1958.655	"
Mice	Rutland, Vt.	43 35	spr. & sum. 1934*	1959.478**	JM 16:156
"	Gdn. Island, Lk. Ont.	43 30	1925	1956.396**	Conf Emp Meteor 1929:121-127
Peromyscus	Tuscola Co. Mich.	43 30	1854	1958.774**	JM 37:121-122
Deer Mouse	Prairie du Sac Wis.	43 17	1929	1956.534**	Ecol Mon 15:1-34
"	" "	43 17	1934(?)	1957.672	"
"	" "	43 17	1938	1957.810	"
"	" "	43 17	1942	1957.948	"
"	" "	43 17		1957.810	(Time Chart)
Meadow Mouse	" "	43 17	1929	1956.534**	Ecol Mon 15:1-34
" "	" "	43 17	1934(?)	1957.672	"
" "	" "	43 17	1938	1957.810	"
" "	" "	43 17	1942	1957.948	"
" "	" "	43 17		1957.810	(Time Chart)
Microtus	New York (state)	43	1919-20	1958.620	J Agr Res 54:779-790
"	" "	43	1923-4	1958.758	"
"	" "	43	1927-8	1958.896**	"
"	" "	43	1931-2	1959.034**	"
"	" "	43	1934-6	1958.172	"
"	" "	43		1958.896**	(Time Chart)
"	Northeastern U.S.	43	1932-6	1957.672	Sci Mon 50:425-434
M montanus	Colo-Pacific NW	42 30	1957-8	1958.000	F & W Serv.
Sage Mouse	Hart Mts. Oregon	42 30	1941	1957.070	JM 24:188-191
Microtus	Ithaca, N.Y.	42 27	1946	1958.086	JM 33:185-189
"	" "	42 27	1951*	1957.293	"
"	" "	42 27	1942-3	1958.448	JM 25:359-364
"	" "	42 27	1943-4*	1957.517	JM 29:35-37

TABLE 2. Continued

SPECIES	PLACE	NORTH LATITUDE ° ′	TIME OF REPORTED HIGH	CURRENT TIMING OF HIGH	SOURCE
Microtus	Ann Arbor, Mich.	42 17	1957-8	1958.000	Original
Peromyscus	“ “	42 17	1957-8	1958.000	“
“Small rodents”	Eastern U.S.	42	1925-6	1956.896	JWM 18:38-45
“ “	“ “	42	1930	1957.534	“
“ “	“ “	42	1933-4	1957.172	“
“ “	“ “	42	1937-8	1957.310	“
“ “	“ “	42	1941-2	1957.448	“
“ “	“ “	42	1945-6	1957.586	“
“ “	“ “	42		1957.310	(Time Chart)
P. pinetorum	Hudson R. Valley	41 30	fall 1931	1958.784	JM 19:163-170
“	“ “	41 30	fall 1935	1958.922**	“
Mice	Wellington, Ohio	41 10	1929-30 winter	1957.034	Ohio Jour Sci 32:403-424
Microtus	Humboldt Co., Calif.	40 45	Sept.1921*	1958.396	JM 6:102-105
P. maniculatus	“ “	40 45	1919	1958.120	JM 4:149-155
“	“ “	40 45	1921*	1958.189	“
“	“ “	40 45	1912*	1956.913**	“
M. californicus	Lassen Co., Calif.	40 30	fall 1923	1958.508	JM 6:102-105
“	“ “	40 30	spr. 1924*	1957.077	“
P. pinetorum	Chester Co. Penn.	40	1935	1958.672	JM 19:163-170
Microtus	Buckeye Lk., Ohio	40	1915	1957.982	Ohio Jour Sci 39:133-143
Mice	Humboldt Valley, Nev.	40	1899-1900	1957.930	J. Agric Res 27:523-535
“	“ “	40	1907	1957.706	“
Pocket Gopher	Grand Mesa, Colo.	39	1943	1958.948**	JM 38:166-267
“ “	“ “	39	1945	1957.086	“
“ “	“ “	39	1948-9	1956.724**	“
“ “	“ “	39	1955	1959.362**	“
“ “	“ “	39		1958.224	(Time Chart)
Mice	Kansas	39	1951	1959.224**	Kan Mus 10:140
Microtus	“	39	1903	1958.024	Kan Agric Col Bull 129
M. haydeni	“	39	1933	1956.672**	Kan Acad Sci 38:351-352
Microtus	Washington, D.C.	38 55	1905-6	1956.206**	Biol Surv Bull 21
“	Albermarle Co., Va.	38 2	Dec.1938	1958.266	JM 23:210
P. pinetorum	“ “	38 2	1938-9	1958.310	“
“	“ “	38 2	1940*	1957.879	“
P. maniculatus	White Mts., Calif.	38	1954	1958.362	JM 36:571-572
Zapus pacificus	Mammoth, Calif.	38	1917*	1958.051	JM 5:25-36
“ “	“ “	38	1922	1957.258	“
Peromyscus	Perry Co., Ill.	38	1936	1959.672**	JM 38:53-59
“	“ “	38	1940	1959.810**	“
“	“ “	38	1944	1959.948**	“
“	“ “	38	1949	1957.224	“
“	“ “	38		1959.948**	(Time Chart)
House Mouse	Davis, Calif.	37 45	1926	1957.396	JM 25:89-90
“ “	“ “	37 45	1941-2	1957.448	JM 30:351-363
Microtus	Central California	37	1916	1958.982**	Calif Agric Exp Circ 79
“	Tulare Co., Calif.	36 20	1923	1958.258	“
“	Visalia, Calif.	36 20	1885	1958.878	“
“	Clarksburg, Calif.	36	1913	1959.844**	“
“	California	36	1927	1958.396	“
Mice	North Carolina	35 40	1946-7*	1956.655**	JM 30:179-192
House Mouse	Kern Co., Calif.	35 30	1926	1957.396	JM 25:89-90
Microtus	Ventura Co., Calif.	34 15	1916	1958.982	Calif Agric Exp Circ 79
“	Los Angeles	34 5	1928	1959.396**	“
“	Pomona	34 3	1917	1959.982**	“
“	Orange Co., Calif.	33 30	1928	1959.396**	
Perognathus longimembris	La Puerta Valley California	33	Apr.1927	1958.184	JM 9:152
Cotton Rat	Thomasville, Ga.	30 50	1926	1957.396	Coop Quail Repts
“ “	“ “	30 50	1934-5	1958.172	“
“ “	“ “	30 50	1939	1958.810	“
“ “	“ “	30 50		1958.172	(Time Chart)

*Low; **Current timing falls outside of centered half of wave length

JM: *Journal of Mammalogy*
JWM: *Journal of Wildlife Management*
NAF: *North American Fauna*
JAE: *Journal of Animal Ecology*

Elton: Charles Elton, *Voles, Mice, and Lemmings*
Leopold GS: Aldo Leopold, *Game Survey of North Central States*
Seton: Ernest Thompson Seton, *Lives of Game Animals*
Other abbreviations seem self explanatory

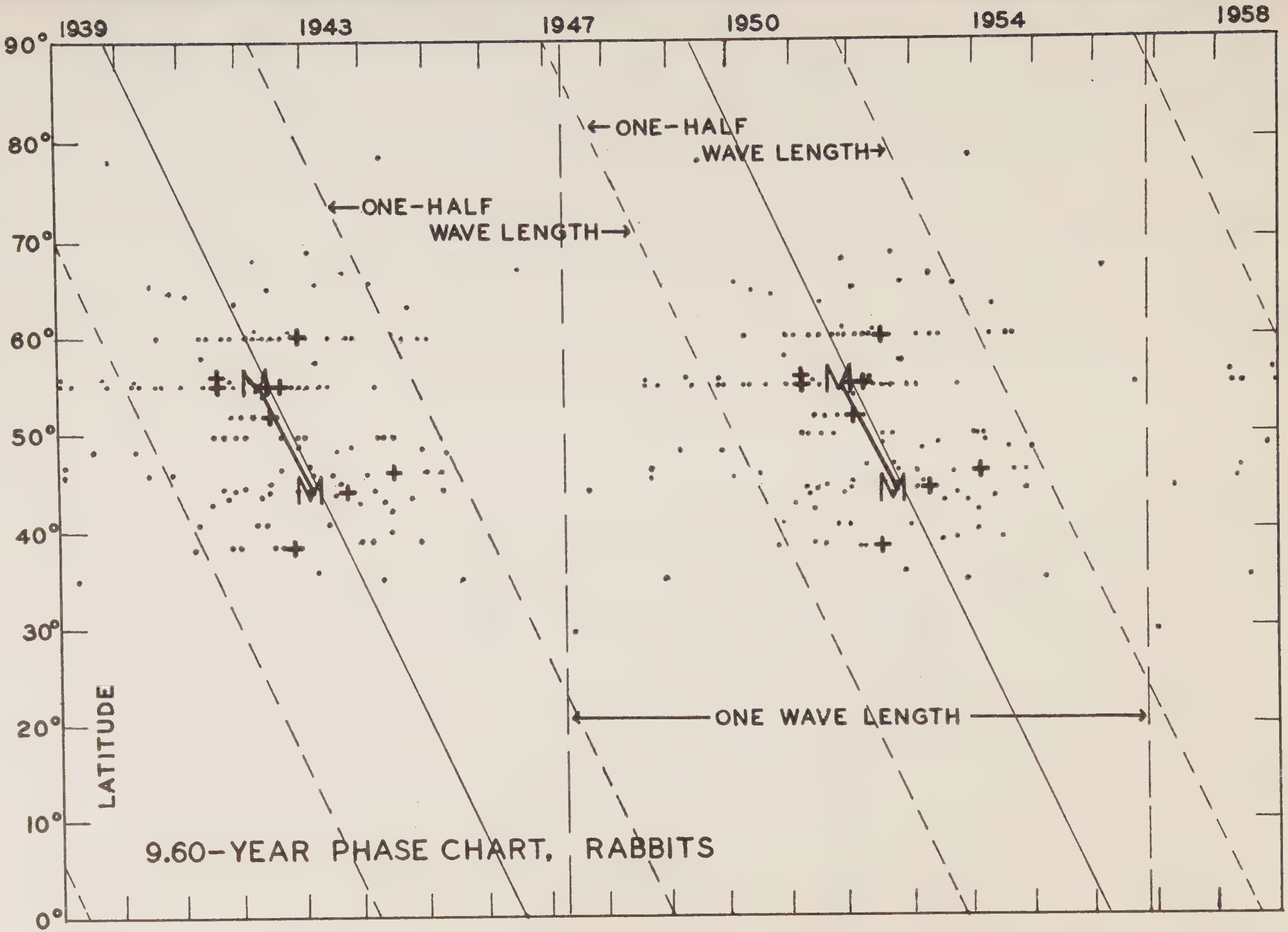


Figure 1. 9.60-year rabbit phase chart (North America) with timing of 1952.1 at 55° North Latitude. The slanting solid line marks the ideal or typical timing. An interval of one-half wave length (i.e., 4.80 years) centered on the passage line is indicated. Indicated also is a space of one wave length (i.e., 9.60 years). Small dots mark timings of "high" from Table 1; time-chart timings are marked by crosses. The respective medians north and south of 50° Latitude are shown by the letters M connected by a heavy line. (Some dots will represent more than one report if the timings and latitudes are the same.)

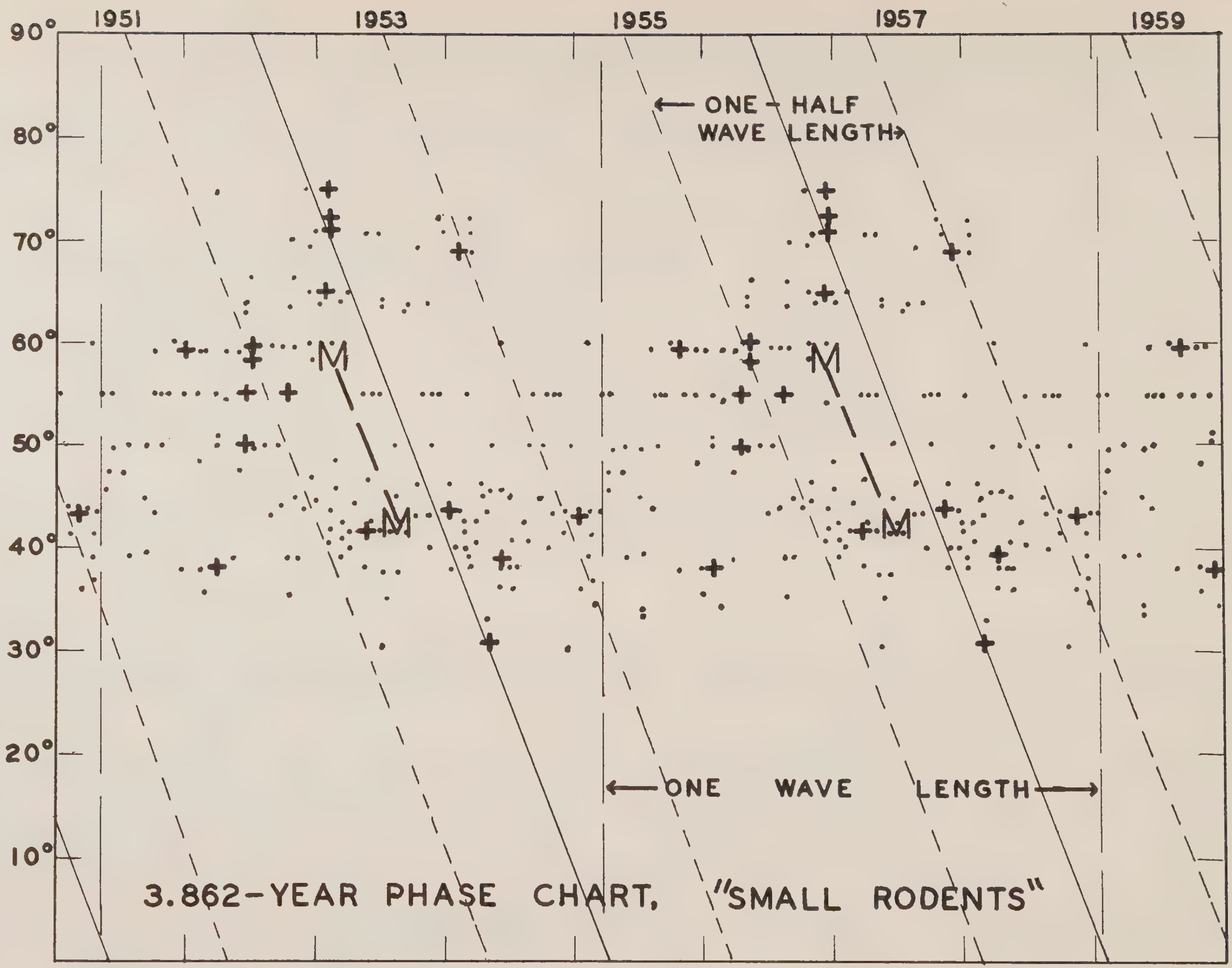


Figure 2. 3.862-year small rodent phase chart (North America) with timing of the Norwegian lemmings (i.e., 1957.134 at 64° 30’ North). The slanting solid line marks ideal or typical passage for this timing. An interval of one-half (3.862 years) centered on the passage line is indicated. Indicated also is a space of one wave length (3.862 years). Timings of “high” from Table 2 are given by small dots; timings from time charts are given by crosses. The respective medians north and south of 50° Latitude are marked by letters M connected by a heavy line. (Some dots will represent more than one report if the timings and latitudes are the same.)

THE 200—YEAR CYCLE IN THE LENGTH OF THE SUNSPOT CYCLE

BY EDWARD R. DEWEY

ABSTRACT

Sunspot maxima tend to come first early and then late in a rhythmic cycle which turns out, 294 B.C. to date, to be exactly 18 sunspot cycles (approximately 199.4 years) long.

The shape of this cycle, on the average, proves to be zigzag. That is, on the average, the sunspot maxima lag for a hundred years at a uniform *rate* to a point (1.58 years behind normal), then advance at a uniform rate to a point an equal time interval ahead of normal. ("Normal" is taken as a 19-item moving average of dates of actual maxima.)

Second and third harmonics (or almost-harmonics) of the 200-year cycle (100-years; 66-years) also seem to be present but are not investigated.

The so-called 80-year cycle noted by others seems to be present over the entire span of 2,253 years, but is not investigated.

The cause of the 200-year cycle could, of course, be chance. It might, however, be a concurrent 11.73-year cycle (1/17 of 199.40 years) which first advances and then retards the sunspot maxima from their normal timing. Such a cycle is suggested by a periodogram of sunspot numbers. If there is such a cycle, its timing, based on a study of the actual sunspot numbers, 1749—1959, comes almost exactly at the time expected on the basis of the above supposition.

The significance of the study lies in part in the discovery that there is a 200-year cycle in the length of the sunspot cycle. The fact that the shape of this cycle is zigzag instead of some other shape that might be supposed, is also important. Increased credence should also perhaps be given to the idea of an 11.73 ± .005-year cycle.

The typical length of the sunspot cycle, 300 B.C. to date, is a shade less than 11.1 years (Dewey, 1958). However, as is well known, this length varies from eight to 17 years. The variation of length is, on its part, cyclic. The dominant cycle of variation is in the general neighborhood of two centuries (Dewey, 1958). That is to say, there is a tendency for sunspot maxima to come early in alternate centuries (in the intervening centuries to come late) in comparison with average or "normal" timing.

The purpose of this paper is to examine this cycle of variations to determine its exact characteristics. For this purpose we will use maxima as determined by Schove (Schove, 1956). See Table 1, Col. B, in which Schove's dates have been posted.

Let us first make an 11.1-year time chart of the dates of sunspot maxima. (Fig. 1.) In this chart we have a series of base numbers across the top of the chart 11.1 years apart, rounded to the nearest integer. The distance down from the top represents years after the base number. Each successive maximum is plotted accordingly. Thus the first base number is at year -301, (302 B.C.). The first of the continuous series of sunspot maxima is at -293, eight years after this base number. This first maximum is, therefore, plotted on the eighth line after (down from) base. The second maximum at -283 is plotted as seven after base of -290, and so on.

Base numbers and dates of sunspot maxima are posted in Table 1, Col. A and Col. B. In accordance with astronomical usage, B.C. dates

TABLE 1: TABULATION SHEET

Col. A: Base numbers 11.1 years apart rounded to the nearest integer (.5 rounded up). The numbers are year and minus year numbers. They go forward from the year -301, arbitrarily.

Col. B: Dates of sunspot maxima (Schove, 1956). (Dates 1600 forward are reduced by .5 for comparability and rounded. Values of .5 are rounded up.)

Col. C: Col. A plus 1,000 to eliminate minus numbers.

Col. D: Col. B plus 1,000 to eliminate minus numbers.

Col. E: Number of years by which maxima follow base numbers. (Curve A of Fig. 1.)

Col. F: 7-year moving average trend of Col. E. (Curve B of Fig. 1.)

Col. G: 19-year moving average trend of Col. G. That is, a 19-year moving average of a 7-year moving average of the lateness of the maxima, after base. (Curve C of Fig. 1.)

Col. H: Col. E minus Col. G. Negative values thus mean maxima *earlier* than trend; positive values mean maxima *later* than trend.

Col. I: Col. F minus Col. G. Negative values mean 7-item moving averages earlier than trend; positive value mean 7-item moving averages later than trend.

A	B	C	D	E	F	G	H	I
Base numbers	Sunspot maxima	Base numbers plus 1,000	Sunspot maxima plus 1,000	Col. D minus Col. C	7-year moving average of Col, E	19-year moving average of Col. F	Col. E minus Col. G	Col. F minus Col. G
-301	-293	699.(3)	707	8				
-290	-283	710	717	7				
-278	-272	722	728	6				
-267	-261	733	739	6	7.71			
-256	-249	744	7.51	7	7.85			
-245	-236	755	764	9	7.85			
-234	-223	766	777	11	8.28			
-223	-214	777	786	9	8.57			
-212	-205	788	795	7	8.57			
-201	-192	799	808	9	7.85			
-190	-182	810	818	8	7.28			
-179	-172	821	828	7	7.43			
-167	-163	833	837	4	7.71	7.85	-3.85	-0.14
-156	-149	844	851	7	7.85	7.75	-0,75	0.10
-145	-135	855	865	10	7.85	7.64	2.36	0.21
-134	-125	866	875	4	8.28	7.54	1.46	0.74
-123	-113	877	887	10	8.85	7.45	2.55	1.40
-112	-104	888	896	8	8.85	7.40	0.60	1.45
-101	-91	899	909	10	8.28	7.40	2.60	0.88
-90	-82	910	918	8	7.43	7.46	0.54	-0.03
-79	-72	921	928	7	6.43	7.57	-0.57	-1.14
-68	-62	932	938	6	6.28	7.70	-1,70	-1.42
-56	-53	944	947	3	5.86	7.81	-4,81	-1,95
-45	-42	955	958	3	5.71	7.90	-4.90	-2.19
-34	-27	966	973	7	6.00	7.96	-0,96	-1.96
-23	-16	977	984	7	6.57	7.99	-0,99	-1.42
-12	-5	988	995	7	7.57	7.97	-0.97	-0.40
-1	8	999	1008	9	8.57	7.95	1.05	0.62
10	2	1010	1020	10	9.00	7.95	2.05	1.05
21	31	1021	1031	10	9.43	7.99	2.01	1.44
32	42	1032	1042	10	9.85	8.10	1.90	0.75
43	53	1043	1053	10	9.85	8.23	1.77	0.63
55	65	1055	1065	10	9.57	8.39	1.61	1.18
66	76	1066	1076	10	9.00	8.56	1.44	0.44
77	86	1077	1086	9	8.71	8.71	0.29	0.00
88	96	1088	1096	8	8.57	8.83	-0.83	-0.26
99	105	1099	1105	6	8.43	8.89	-2.89	-0.46
110	118	1110	1118	8	8.28	8.89	-0.89	-0.61
121	130	1121	1130	9	8.28	8.89	0.11	-0.61
132	141	1132	1141	9	8.43	8.90	0.10	-0.47
143	152	1143	1152	9	8.85	8.92	0.08	-0.07
154	163	1154	1163	9	8.85	8.97	0.03	-0.12
166	175	1166	1175	9	8.85	9.06	-0.06	-0.21
177	186	1177	1186	9	8.85	9.20	-0.20	-0.35

Note: The first base number (Col. A) was actually -334.0 which, minus 11.1 successively, gives -300.7, or -301 rounded, as noted here. -300.7 + 1000 is 699.3 (Col. C) or 699 rounded.

TABLE 1. Continued

A	B	C	D	E	F	G	H	I
Base numbers	Sunspot maxima	Base numbers plus 1,000	Sunspot maxima plus 1,000	Col. D minus Col. C	7-year moving average of Col. E	19-year moving average of Col. F	Col. E minus Col. G	Col. F minus Col. G
188	196	1188	1196	8	8.85	9.36	-1.36	-0.51
199	208	1199	1208	9	8.71	9.52	-0.52	-0.81
210	219	1210	1219	9	8.71	9.67	-0.67	-0.96
221	230	1221	1230	9	9.00	9.80	-0.80	-0.80
232	240	1232	1240	8	9.57	9.88	-1.88	-0.31
243	252	1243	1252	9	10.14	9.94	-0.94	0.20
254	265	1254	1265	11	10.85	9.95	1.05	0.90
265	277	1265	1277	12	11.28	9.98	2.02	1.30
277	290	1277	1290	13	11.71	10.02	2.98	1.69
288	302	1288	1302	14	11.71	10.04	3.96	1.67
299	311	1299	1311	12	11.57	10.07	1.93	1.50
310	321	1310	1321	11	11.42	10.13	0.87	1.29
321	330	1321	1330	9	10.71	10.18	-1.18	0.53
332	342	1332	1342	10	9.71	10.26	-0.26	-0.55
343	354	1343	1354	11	9.57	10.34	0.66	-0.77
354	362	1354	1362	8	9.14	10.40	-2.40	-1.26
365	372	1365	1372	7	9.43	10.46	-3.46	-1.03
376	387	1376	1387	11	9.57	10.51	0.49	-0.94
388	396	1388	1396	8	9.28	10.55	-2.55	-1.27
399	410	1399	1410	11	9.43	10.58	0.42	-1.15
410	421	1410	1421	11	9.71	10.61	0.39	-0.90
421	430	1421	1430	9	9.71	10.65	-1.65	-0.94
432	441	1432	1441	9	10.57	10.72	-1.72	-0.15
443	452	1443	1452	9	11.00	10.82	-1.82	0.18
454	465	1454	1465	11	11.42	10.91	0.09	0.51
465	479	1465	1479	14	11.85	11.01	2.99	0.84
476	490	1476	1490	14	12.28	11.09	2.91	1.19
487	501	1487	1501	14	12.42	11.10	2.90	1.32
499	511	1499	1511	12	12.28	11.11	0.89	1.17
510	522	1510	1522	12	12.28	11.09	0.91	1.19
521	531	1521	1531	10	12.14	11.08	-1.08	1.06
532	542	1532	1542	10	12.00	11.08	-1.08	0.92
543	557	1543	1557	14	11.57	11.06	2.94	0.51
554	567	1554	1567	13	11.28	11.06	1.94	0.22
565	578	1565	1578	13	11.14	11.09	1.91	0.05
576	585	1576	1585	9	10.85	11.15	-2.15	-0.30
587	597	1587	1597	10	9.85	11.20	-1.20	-1.35
598	607	1598	1607	9	9.43	11.26	-2.26	-1.83
610	618	1610	1618	8	9.14	11.32	-3.32	-2.18
621	628	1621	1628	7	9.43	11.37	-4.37	-1.94
632	642	1632	1642	10	9.71	11.41	-1.41	-1.70
643	654	1643	1654	11	10.28	11.43	-0.43	-1.15
654	665	1654	1665	11	10.85	11.43	-0.43	-0.58
665	677	1665	1677	12	12.14	11.43	0.57	0.71
676	689	1676	1689	13	12.85	11.43	1.57	1.42
687	699	1687	1699	12	13.28	11.43	0.57	1.85
698	714	1698	1714	16	13.57	11.46	4.54	2.11
709	724	1709	1724	15	13.42	11.49	3.51	1.93
721	735	1721	1735	14	13.14	11.50	2.50	1.64
732	745	1732	1745	13	13.00	11.47	1.53	1.53
743	754	1743	1754	11	12.28	11.42	-0.42	0.86
754	765	1754	1765	11	11.71	11.34	-0.34	0.37
765	776	1765	1776	11	11.28	11.23	-0.23	0.05
776	787	1776	1787	11	11.14	11.05	-0.05	0.09
787	798	1787	1798	11	10.85	10.82	0.18	0.03
798	809	1798	1809	11	10.42	10.57	0.43	-0.15
809	821	1809	1821	12	9.85	10.30	1.70	-0.45

TABLE 1. Continued

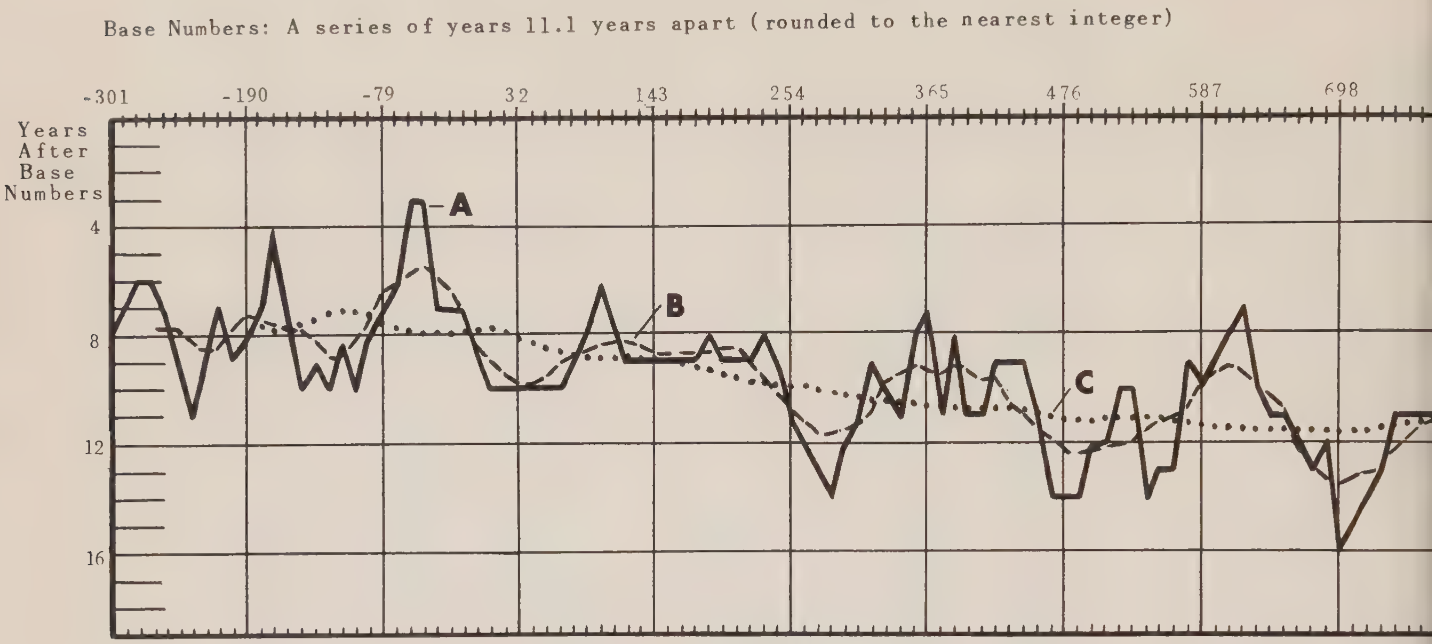
A Base numbers	B Sunspot maxima	C Base numbers plus 1,000	D Sunspot maxima plus 1,000	E Col. D minus Col. C	F 7-year moving average of Col. E	G 19-year moving average of Col. F	H Col. E minus Col. G	I Col. F minus Col. G
820	829	1820	1829	9	9.43	10.02	-1.02	-0.59
832	840	1832	1840	8	8.85	9.74	-1.74	-0.89
843	850	1843	1850	7	8.85	9.48	-2.48	-0.63
854	862	1854	1862	8	8.71	9.25	-1.25	-0.54
865	872	1865	1872	7	8.71	9.04	-2.04	-0.33
876	887	1876	1887	11	8.71	8.85	2.15	-0.14
887	898	1887	1898	11	8.57	8.67	2.33	-0.10
898	907	1898	1907	9	8.43	8.49	0.51	-0.06
909	917	1909	1917	8	8.43	8.34	-0.34	0.09
920	926	1920	1926	6	8.14	8.24	-2.24	-0.10
931	938	1931	1938	7	7.85	8.21	-1.21	-0.36
943	950	1943	1950	7	8.00	8.26	-1.26	-0.26
954	963	1954	1963	9	7.85	8.35	0.65	-0.50
965	974	1965	1974	9	7.71	8.47	0.53	-0.76
976	986	1976	1986	10	7.71	8.62	1.38	-0.91
987	994	1987	1994	7	7.71	8.75	-1.75	-1.04
998	1003	1998	2003	5	7.43	8.85	-3.85	-1.42
1009	1016	2009	2016	7	7.57	8.92	-1.92	-1.35
1020	1027	2020	2027	7	8.00	8.96	-1.96	-0.96
1031	1038	2031	2038	7	8.85	8.99	-1.99	-0.14
1042	1052	2042	2052	10	9.85	9.01	0.99	0.84
1054	1067	2054	2067	13	10.42	9.01	3.99	1.41
1065	1078	2065	2078	13	11.14	8.97	4.03	2.17
1076	1088	2076	2088	12	11.42	8.96	3.04	2.46
1087	1098	2087	2098	11	11.28	8.95	2.05	2.33
1098	1110	2098	2110	12	10.42	8.94	3.06	1.48
1109	1118	2109	2118	9	9.85	8.94	0.06	0.91
1120	1129	2120	2129	9	9.14	8.91	0.09	0.23
1131	1138	2131	2138	7	8.71	8.90	-1.90	-0.19
1142	1151	2142	2151	9	8.28	8.91	0.09	-0.63
1153	1160	2153	2160	7	7.85	8.86	-1.86	-1.01
1165	1173	2165	2173	8	7.14	8.79	-0.79	-1.65
1176	1185	2176	2185	9	7.57	8.68	0.32	-1.11
1187	1193	2187	2193	6	7.43	8.53	-2.53	-1.10
1198	1202	2198	2202	4	7.57	8.38	-4.38	-0.81
1209	1219	2209	2219	10	7.43	8.28	1.72	-0.85
1220	1228	2220	2228	8	7.00	8.18	-0.18	-1.18
1231	1239	2231	2239	8	7.85	8.11	-0.11	-0.26
1242	1249	2242	2249	7	9.00	8.05	-1.05	0.95
1253	1259	2253	2259	6	8.85	7.98	-1.98	0.87
1264	1276	2264	2276	12	9.14	7.93	4.07	1.21
1276	1288	2276	2288	12	9.00	7.91	4.09	1.09
1287	1296	2287	2296	9	8.57	7.85	1.15	0.72
1298	1308	2298	2308	10	8.57	7.79	2.21	0.78
1309	1316	2309	2316	7	8.43	7.72	-0.72	0.71
1320	1324	2320	2324	4	8.00	7.66	-3.66	0.34
1331	1337	2331	2337	6	7.85	7.65	-1.65	0.20
1342	1353	2342	2353	11	7.43	7.60	3.40	-0.17
1353	1362	2353	2362	9	7.00	7.51	1.49	-0.51
1364	1372	2364	2372	8	7.00	7.41	0.59	-0.41
1375	1382	2375	2382	7	6.71	7.32	-0.32	-0.61
1387	1391	2387	2391	4	6.43	7.23	-3.23	-0.80
1398	1402	2398	2402	4	6.28	7.17	-3.17	-0.89
1409	1413	2409	2413	4	6.14	7.10	-3.10	-0.96
1420	1429	2420	2429	9	6.28	7.03	1.97	-0.75
1431	1439	2431	2439	8	6.85	7.00	1.00	-0.15
1442	1449	2442	2449	7	7.00	6.97	0.03	0.03

TABLE 1. Continued

A	B	C	D	E	F	G	H	I
Base numbers	Sunspot maxima	Base numbers plus 1,000	Sunspot maxima plus 1,000	Col. D minus Col. C	7-year moving average of Col. E	19-year moving average of Col. F	Col. E minus Col. G	Col. F minus Col. G
1453	1461	2453	2461	8	7.28	6.93	1.07	0.35
1464	1472	2464	2472	8	7.00	6.90	1.10	0.10
1475	1480	2475	2480	5	7.28	6.85	− 1.85	0 43
1486	1492	2486	2492	6	7.43	6.82	− 0.82	0 61
1498	1505	2498	2505	7	7.43	6.83	0.17	0.60
1509	1519	2509	2519	10	7.14	6.84	3.16	0.30
1520	1528	2520	2528	8	7.14	6.86	1.14	0.28
1531	1539	2531	2539	8	7.43	6.92	1.08	0.51
1542	1548	2542	2548	6	7.28	6.97	− 0.97	0.31
1553	1558	2553	2558	5	6.57	7.02	− 2.02	− 0.45
1564	1572	2564	2572	8	6.43	7.08	0.92	− 0 65
1575	1581	2575	2581	6	6.14	7.16	− 1.16	− 1 02
1586	1591	2586	2591	5	6.14	7.23	− 2.23	− 1.09
1597	1604	2597	2604	7	6.57	7.29	− 0.29	− 0 72
1609	1615	2609	2615	6	6.43	7.33	− 1.33	− 0.90
1620	1626	2620	2626	6	6.57	7.36	− 1.36	− 0.79
1631	1639	2631	2639	8	7.43	7.39	0.61	0.04
1642	1649	2642	2649	7	7.85	7.35	− 0.35	0.50
1653	1660	2653	2660	7	8.00	7.27	− 0.27	0.73
1664	1675	2664	2675	11	8.28	7.23	3.77	1.05
1675	1685	2675	2685	10	8.57	7.21	2.79	1.36
1686	1693	2686	2693	7	8.57	7.22	− 0.22	1 35
1697	1705	2697	2705	8	8.57	7.21	0.79	1.36
1708	1718	2708	2718	10	8.14	7.19	2.81	0 95
1720	1727	2720	2727	7	7.85	7 20	− 0.20	0.65
1731	1738	2731	2738	7	7.57	7.24	− 0.24	0.33
1742	1750	2742	2750	8	6.85	7.23	0.77	− 0 38
1753	1761	2753	2761	8	5.71	7.20	0.80	− 1.49
1764	1769	2764	2769	5	5.85	7.17	− 2.17	− 1 32
1775	1778	2775	2778	3	6.00	7.14	− 4.14	− 1.14
1786	1788	2786	2788	2	6.28	7.11	− 5.11	− 0 83
1797	1805	2797	2805	8	6.00	7.09	0.91	− 1.09
1808	1816	2808	2816	8	6.14	7.06	0.94	− 0 92
1819	1829	2819	2829	10	6.71	7 03	2.97	− 0 32
1831	1837	2831	2837	6	7.28			
1842	1848	2842	2848	6	7.28			
1853	1860	2853	2860	7	7.28			
1864	1870	2864	2870	6	7.28			
1875	1883	2875	2883	8	7.71			
1886	1894	2886	2894	8	8.14			
1897	1907	2897	2907	10	8.14			
1908	1917	2908	2917	9	8.00			
1919	1928	2919	2928	9				
1930	1937	2930	2937	7				
1942	1947	2942	2947	5				
1953	1957	2953	2957	4				

FIG. 1: DATES OF SUNSPOT MAXIMA:

AN 11.1-YEAR TIME CHART OF THE DATES OF SUNSPOT MAXIMA



are listed as negative numbers. As there is no year zero in the B.C.—A.D. system, the negative numbers always have a numerical value one less than the B.C. numbers. That is, the year minus 9, for example, is equivalent to the year 10 B.C.

To eliminate negative numbers, the constant of 1,000 has been added to all the years shown in Col. A and Col. B. The results are posted in Col. C and Col. D respectively.

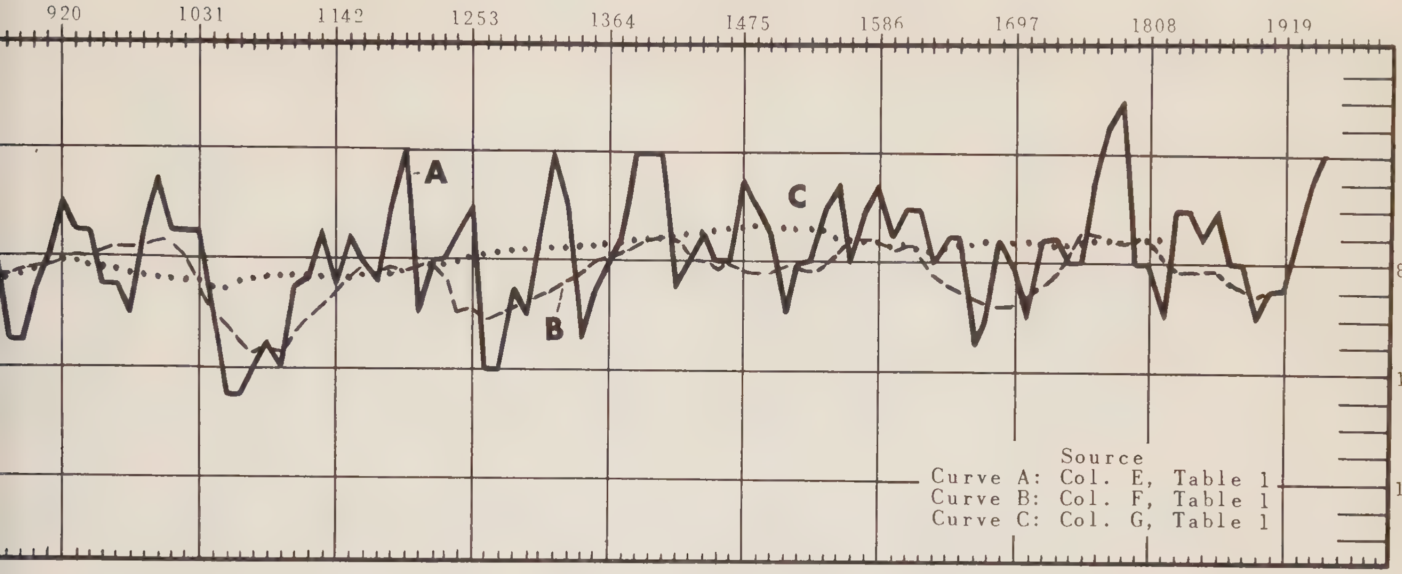
Note that base numbers and years of sunspot maxima refer to the midpoint of the year. From year 1600 forward, where the years of sunspot maxima are given in years and decimal years, .5 has been subtracted to make the values comparable with the earlier figures. The dates so obtained are rounded. Values of .5 are rounded up.

The years by which maxima follow base numbers are posted in Table 1, Col. E.

Study of Fig. 1 shows a cyclic tendency about seven intervals long. That is, every seven points or so on the time chart tend to come earlier, with intervening points coming later. As each point on the time chart represents one 11.1-year sunspot cycle, this suggests a 77.7 plus or minus year variation in the length of the sunspot cycle. This variation is perhaps the 83-year cycle in the length of the sunspot cycle suggested by H. W. Clough (Clough, 1933), or the 80-year cycle in the length of the sunspot cycles suggested by W. Gleissberg (Gleissberg, 1958). To remove this seven interval cycle, we compute a centered 7-item moving average of the time chart values (Table 1, Col. F). The results are shown by the broken line in Fig. 1. A cyclic tendency of about 18 of the 11.1-year intervals is clearly visible by inspection of the broken line in Fig. 1 representing the 7-item moving average of the time chart values. Graduated scale analysis suggests an approximate length of 18¼ intervals.

To isolate this cycle we now compute a 19-item centered moving average of the 7-item moving average of the time chart values (years after base) and post the averages in Table 1, Col. G. The 19-item moving average is plotted in Fig. 1 as Curve C. We then express the time chart values as differences above and below the 19-item moving average trend thus computed. These differences are called deviations. They are posted in Table 1, Col. H, and charted in Fig. 2, Curve A. These deviations are put, experimentally, into an 18¼-item periodic table. (It does not seem

A chart of (A) the intervals by which dates of sunspot maxima follow a series of base numbers 11.1 years apart (rounded to the nearest integer)—together with (B) a 7-item centered moving average of the intervals, and (C) a 19-item moving average trend of the 7-item moving average.



necessary to reproduce this table as it is only a first approximation. For an example of a periodic table see Table 2 where an 18-item periodic table is illustrated.)

This 18¼-item table is then averaged by halves. The values of each half are in turn smoothed by a 6-item moving average of a 3-item moving average. The results are plotted as shown in Fig. 3. (The scale is inverted to correspond to the scale of the time chart.) It is clear that the smoothed averages of the second half of the 18¼-item periodic table crest and trough slightly to the left of the smoothed averages of the first half of the table.

A plotting on enlarged scale (not illustrated) shows that the slippage amounts to 1.4 intervals. As there are five lines of figures in each half of the periodic table, there are five "200-year" cycles between the averages representing the first half and the averages representing the second half of the data. Thus the slippage amounts to 1.4 ÷ 5 or .28 of an interval per "200-year" cycle. The first approximation of the length of the "200-year" cycle is thus shown to be 18.25 - .28 or 17.97 intervals. As each interval is 11.1 years long we have a first approximation of 199.47 years.

We now construct an 18-item periodic table, (Table 2); average by halves; smooth each of the averages by a 6-item moving average of a 6-item moving average; and plot the result in Fig. 4. (Scale inverted.) We now plot these values equalized around the X-axis on a greatly enlarged and finely subdivided scale (not shown). Measuring from crossover to crossover we position each half of the periodic table. We find no slippage whatever between halves. It thus appears that the length of the so-called 200-year cycle is as close to 18 sunspot cycles as can be measured by this method.

Let us now determine shape, strength, timing, and length in years of this so-called 200-year cycle in the length of the sunspot cycle. I shall then speculate in regard to cause.

SHAPE, STRENGTH, AND TIMING

The averages of all the various columns of the 18-item periodic table are charted in Fig. 5, Curve A. (The curve is repeated in phantom. Scale is inverted.) We can rid these values of the worst randoms by dropping the high and the low value in each column and averaging the remaining eight values. This

FIG. 2: DEVIATIONS FROM THE 19-ITEM MOVING AVERAGE

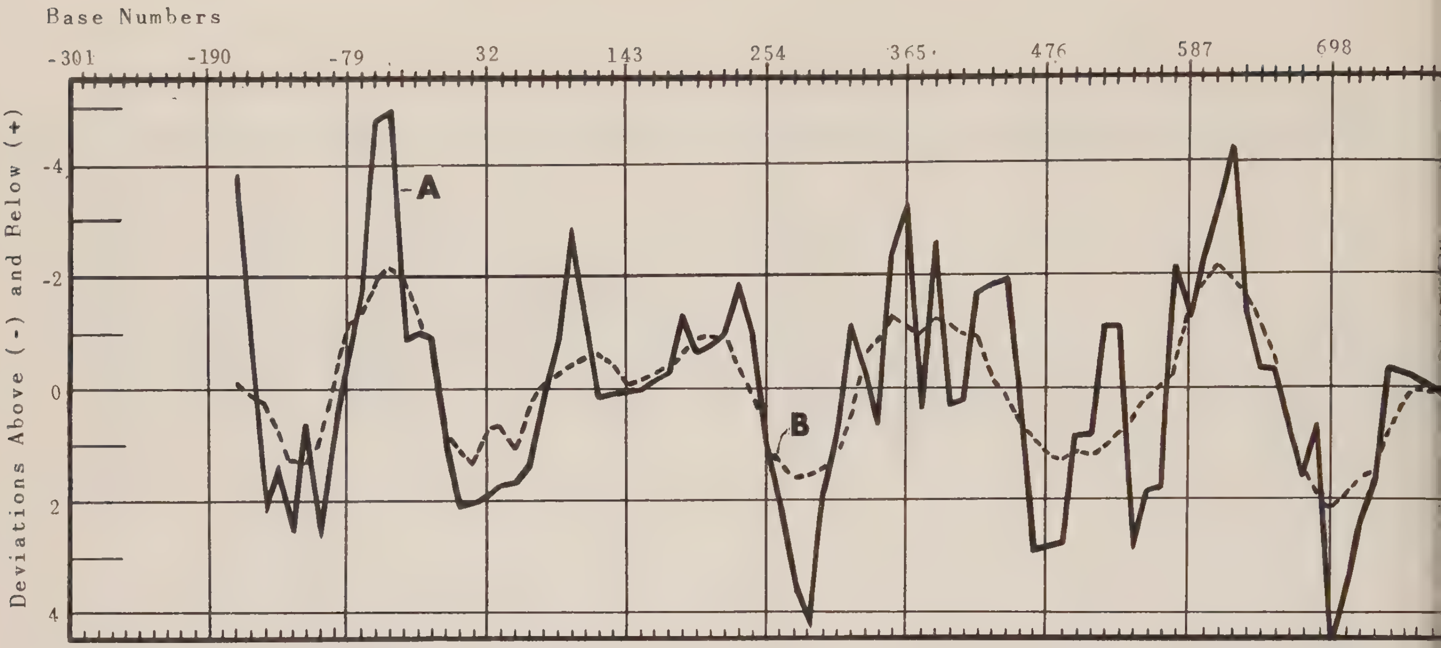
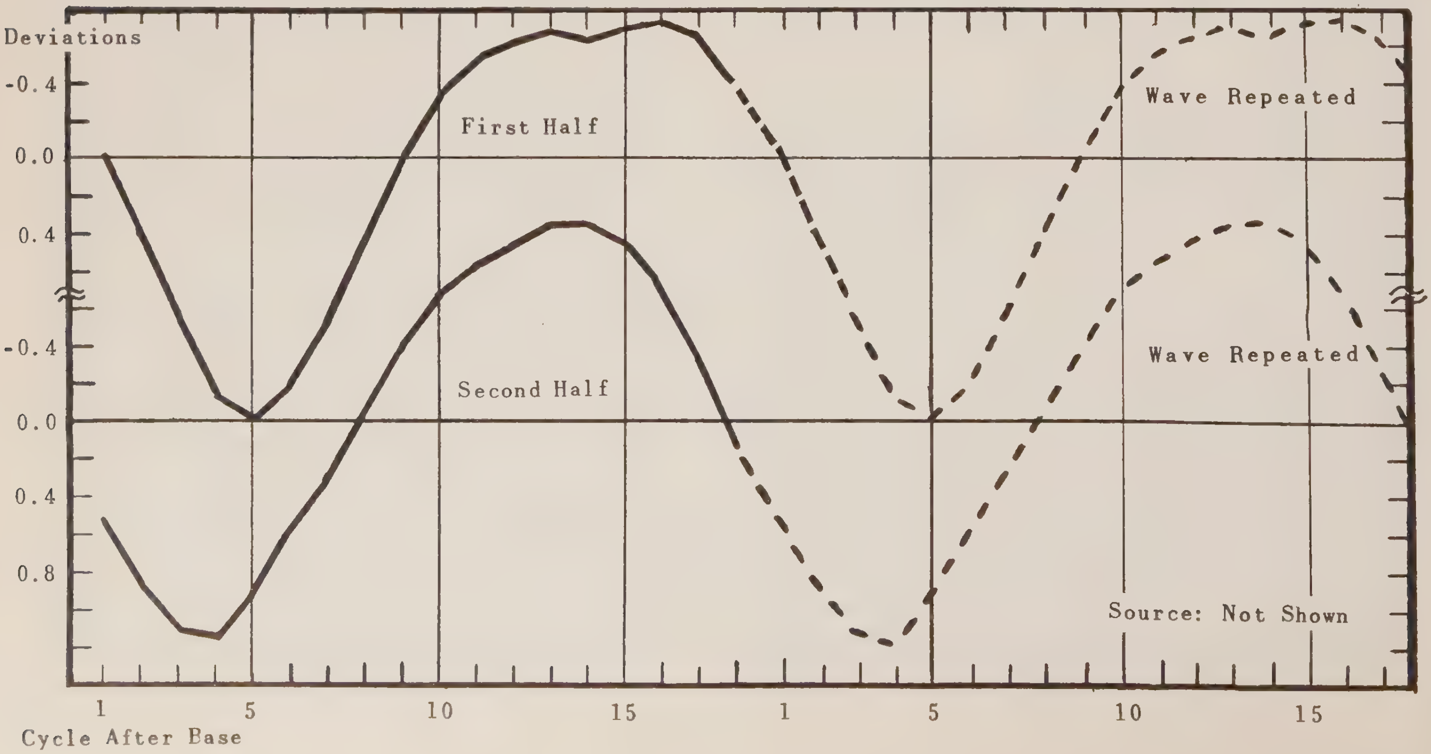


Fig. 3: Average of the first and of the second halves of the 18¼-item periodic table of the deviations, smoothed by a 6-item moving average of a 3-item moving average.

Note that the scale is reversed to conform to the scale of the time chart.

Note that the curve representing the second half of the periodic table lies slightly to the left of the curve representing the first half.

From this slippage it can be calculated that the 18¼-item length is too long by about a quarter of an interval. See text.

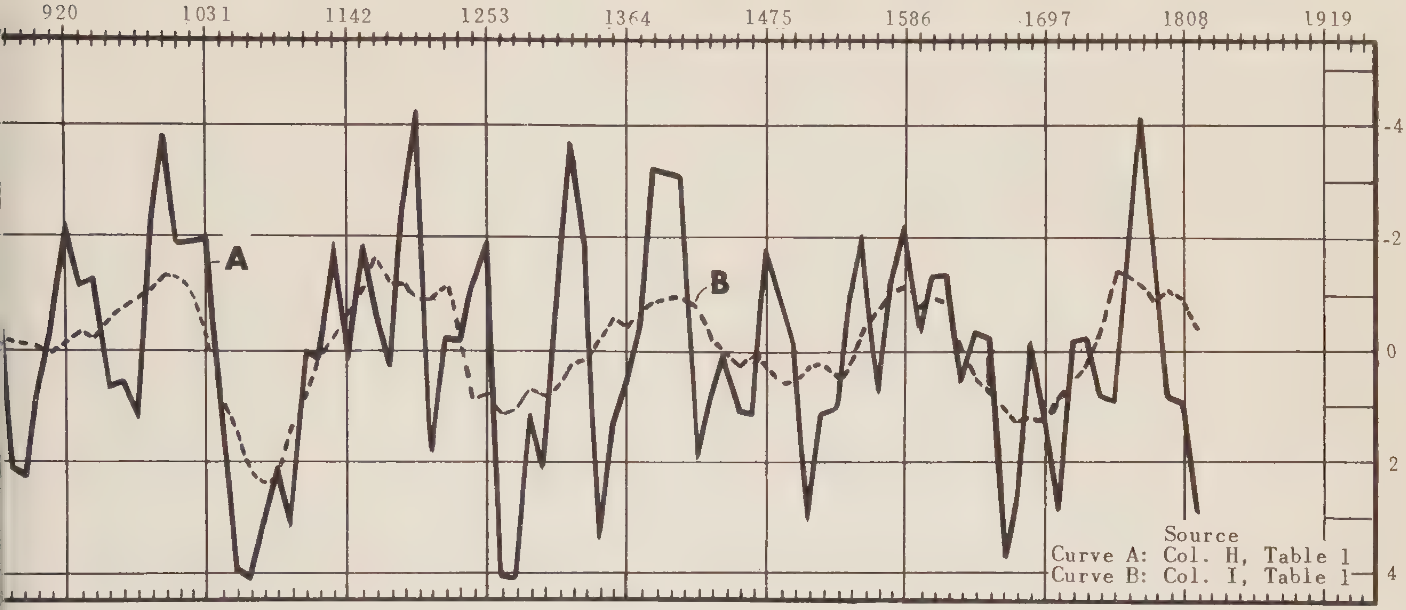


Source: Not Shown

Fig. 2 shows the amounts by which the values of Curve A and Curve B of Fig. 1 are above or below the 19-item moving average, considered as an axis.

Curve A: Deviations of the actual values from the 19-item moving average.

Curve B: Deviations of the 7-item moving average from the 19-item moving average of the 7-item moving average.

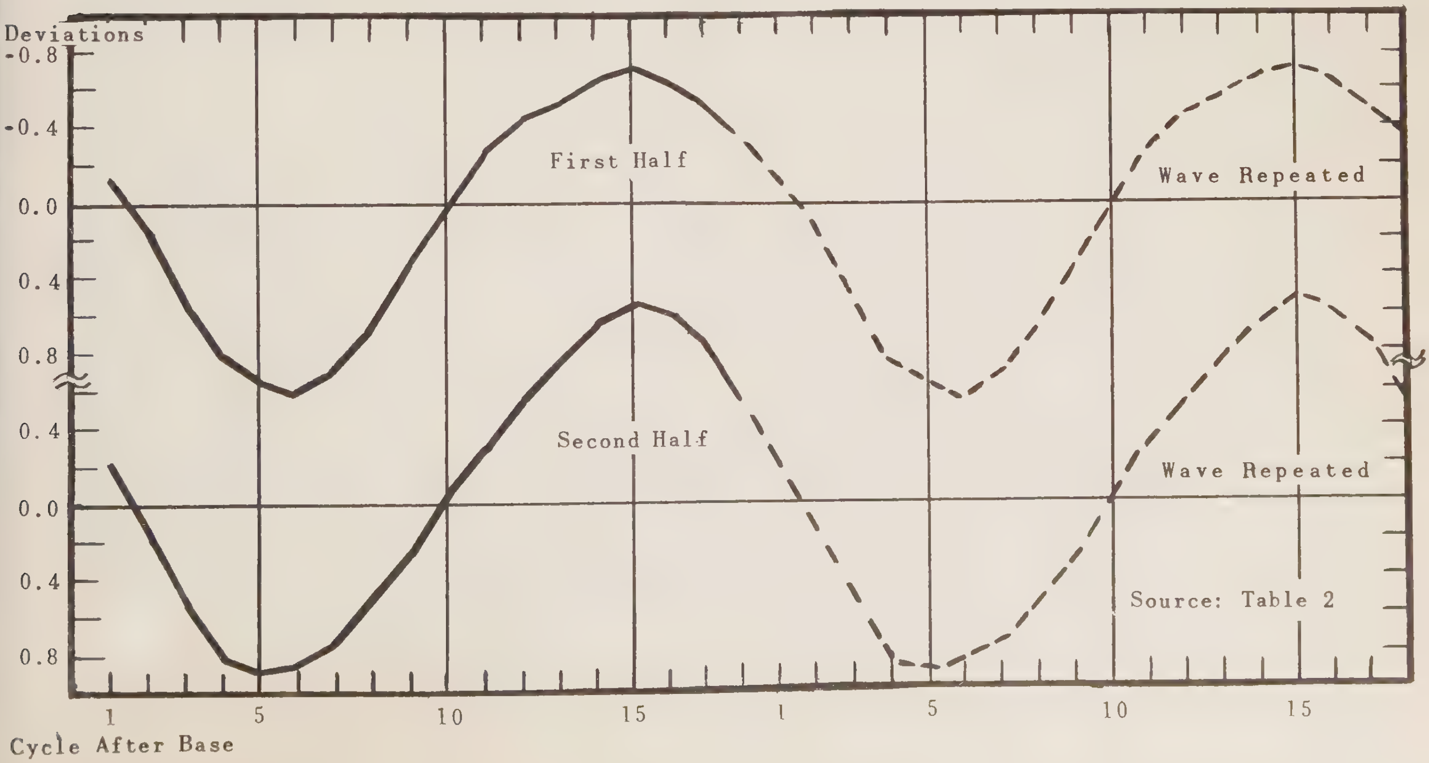


Source
Curve A: Col. H, Table 1
Curve B: Col. I, Table 1

Fig. 4: Average of the first and second halves of the 18-item periodic table of the deviations, smoothed by a 6-item moving average of a 6-item moving average.

Note that the scale is inverted.

Note that the two curves lie directly under each other. This fact confirms the length of the 200-year cycle in the variation in the length of the sunspot cycle as being exactly 18 sunspot intervals long.



Source: Table 2

TABLE 2: AN 18-ITEM PERIODIC TABLE OF THE DEVIATIONS

This table has been averaged by halves and the averages smoothed. It has also been averaged entire, and entire ex the highest and lowest value in each column. These last named values have also been smoothed.

Base Years	11.1-Year Intervals After Base 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
821	-3.85	-0.75	2.36	1.46	2.55	0.60	2.60	0.54	-0.57	-1.70	-4.81	-4.90	-0.96	-0.99	-0.97	1.05	2.05	2.01
1021	1.90	1.77	1.61	1.44	0.29	-0.83	-2.89	-0.89	0.11	0.10	0.08	0.03	-0.06	-0.20	-1.36	-0.52	-0.67	-0.80
1221	-1.88	-0.94	1.05	2.02	2.98	3.96	1.93	0.87	-1.18	-0.26	0.66	-2.40	-3.46	0.49	-2.55	0.42	0.39	-1.65
1421	-1.72	-1.82	0.09	2.99	2.91	2.90	0.89	0.91	-1.08	-1.08	2.94	1.94	1.91	-2.15	-1.20	-2.26	-3.32	-4.37
1621	-1.41	-0.43	-0.43	0.57	1.57	0.57	4.54	3.51	2.50	1.53	-0.42	-0.34	-0.23	-0.05	0.18	0.43	1.70	-1.02
1820	-1.74	-2.48	-1.25	-2.04	2.15	2.33	0.51	-0.34	-2.24	-1.21	-1.26	0.65	0.53	1.38	-1.75	-3.85	-1.92	-1.96
2020	-1.99	0.99	3.99	4.03	3.04	2.05	3.06	0.06	0.09	-1.90	0.09	-1.86	-0.79	0.32	-2.53	-4.38	1.72	-0.18
2220	-0.11	-1.05	1.98	4.07	4.09	1.15	2.21	-0.72	-3.36	-1.65	3.40	1.49	0.59	-0.32	-3.23	-3.17	-3.10	1.97
2420	1.00	0.03	1.07	1.10	-1.85	-0.82	0.17	3.16	1.14	1.08	-0.97	-2.02	0.92	-1.16	-2.23	-0.29	-1.33	-1.36
2620	0.61	-0.35	-0.27	3.77	2.79	-0.22	0.79	2.81	-0.20	-0.24	0.77	0.80	-2.17	-4.14	-5.11	0.91	0.94	(2.97)
A	-1.39	-0.43	0.94	1.70	2.06	1.44	1.41	0.99	-0.04	-0.28	-0.31	-1.13	-0.56	-0.58	-1.18	-0.18	0.03	-1.17
B	-0.05	0.29	0.72	1.19	1.42	1.26	0.93	0.54	0.11	-0.22	-0.48	-0.67	-0.66	-0.60	-0.61	-0.74	-0.72	-0.37
C	-0.14	0.18	0.53	0.81	0.97	1.01	0.91	0.67	0.36	0.04	-0.23	-0.42	-0.54	-0.63	-0.67	-0.62	-0.51	-0.37
D	-0.45	-0.57	0.31	2.19	2.04	0.90	1.35	0.99	-0.91	-0.78	0.41	-0.19	-0.18	-0.78	-2.97	-2.16	-0.74	0.29
E	0.17	0.64	0.74	1.04	1.30	1.09	0.60	0.33	0.15	-0.11	-0.40	-0.75	-0.98	-1.17	-1.09	-1.13	-1.10	-0.55
F	-0.20	0.16	0.56	0.83	0.90	0.85	0.75	0.56	0.28	-0.03	-0.29	-0.54	-0.75	-0.92	-1.04	-1.00	-0.81	-0.51
G	-0.92	-0.50	0.62	1.94	2.05	1.17	1.38	0.99	-0.48	-0.53	0.05	-0.66	-0.37	-0.68	-2.08	-1.17	-0.35	-0.44
H	-0.91	-0.54	0.53	2.17	2.29	1.07	1.52	0.91	-0.49	-0.62	-0.12	-0.46	-0.27	-0.51	-1.98	-1.04	-0.28	-0.37
I	0.10	0.53	0.77	1.17	1.41	1.24	0.78	0.28	0.12	-0.17	-0.41	-0.66	-0.73	-0.76	-0.74	-0.85	-0.85	-0.43
J	-0.17	0.32	0.65	0.97	1.29	1.33	1.01	0.58	0.25	-0.03	-0.29	-0.54	-0.70	-0.75	-0.75	-0.80	-0.85	-0.64
K	0.00	0.23	0.43	0.59	0.69	0.71	0.64	0.51	0.32	0.10	-0.14	-0.34	-0.50	-0.59	-0.61	-0.54	-0.41	-0.24
L	-0.05	0.18	0.38	0.55	0.64	0.66	0.59	0.46	0.28	0.05	-0.19	-0.39	-0.54	-0.64	-0.66	-0.59	-0.46	-0.28

Source
Table 1, Col. F

A. Average, first five cycles.
B. Centered 6-item moving average of line A.
C. Centered 6-item moving average of line B.
D. Average, second five cycles.
E. Centered 6-item moving average of line D.
F. Centered 6-item moving average of line E.
G. Average, all 10 cycles.
H. Line G minus the highest and lowest values (an 8-term modified mean).
I. Centered 6-item moving average of line H.
J. Centered 2-item moving average of line I.
K. Centered 9-item moving average of line J.
L. Line K values plus .047 to equalize around 0.00 (the final smoothed cycle).

has been done and the results are plotted in Fig. 5, Curve B. There is no substantial change in the shape of the average cycle.

The curve in Fig. 5 B represents (a) the 18-item cycle, (b) other cycles that may not have been washed out by the averaging process, and (c) randoms not already eliminated.

Examination of the curve shows suggestions of 6-item and 9-item cycles. Whether these variations are the result of real cycles, or are merely artifacts, cannot be known without more work than I have time for in connection with this paper. However, in either event, they can be eliminated by a 9-item moving average of a 2-item moving average of a 6-item moving average of the values charted in Fig. 5, Curve B. These have been computed with the result shown in Fig. 6. (Scale inverted.)

The moving averages will have completely *removed* the 6-item and 9-item tendencies, and will have *modified* the 18-item cycle. As the 6-item and 9-item tendencies are removed by

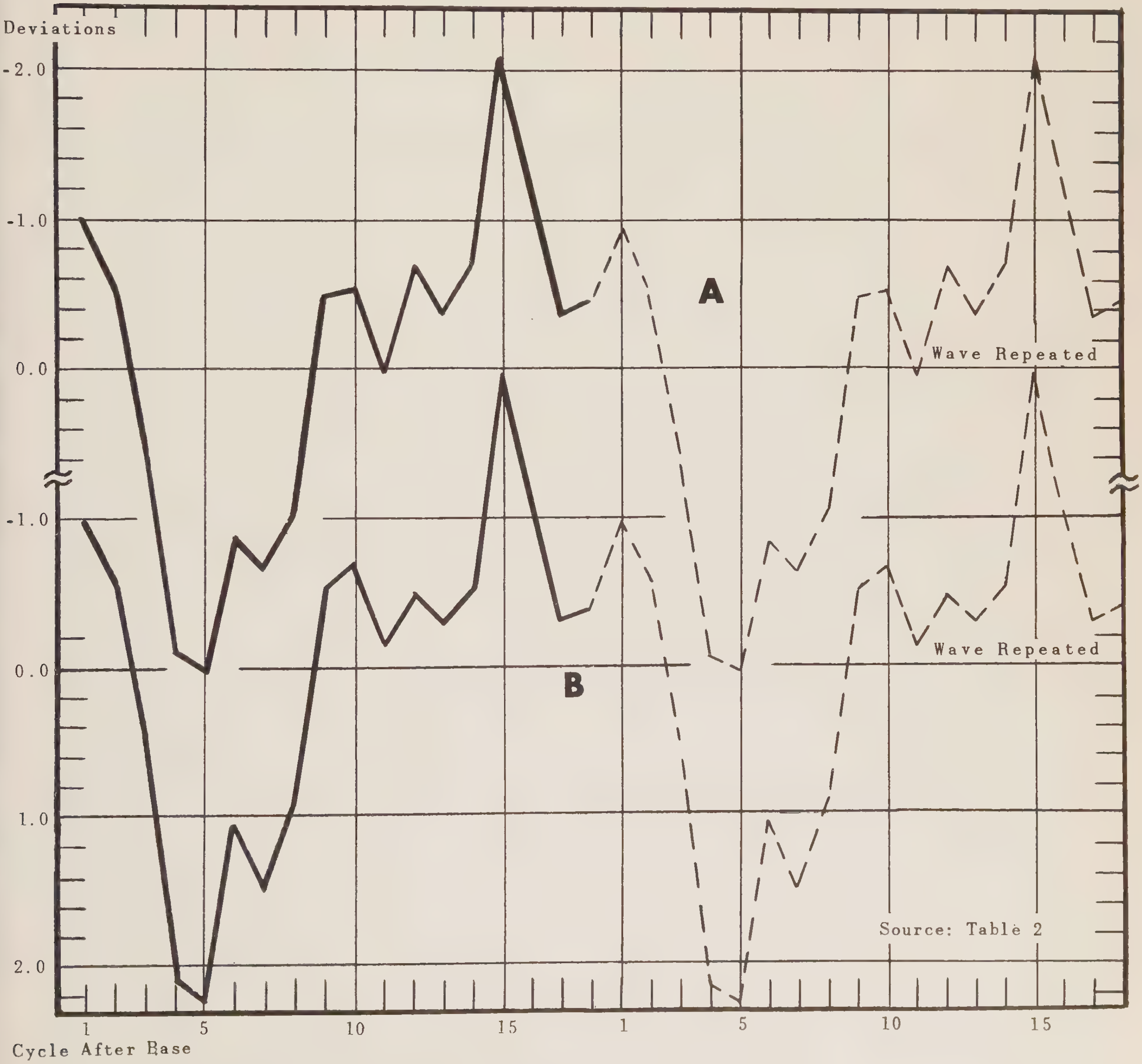


FIG. 5: Average of the entire 18-item periodic table.
Curve A: The mean of each column.
Curve B: The modified mean of each column. (The mean of each column ex the highest and lowest value in that column.)

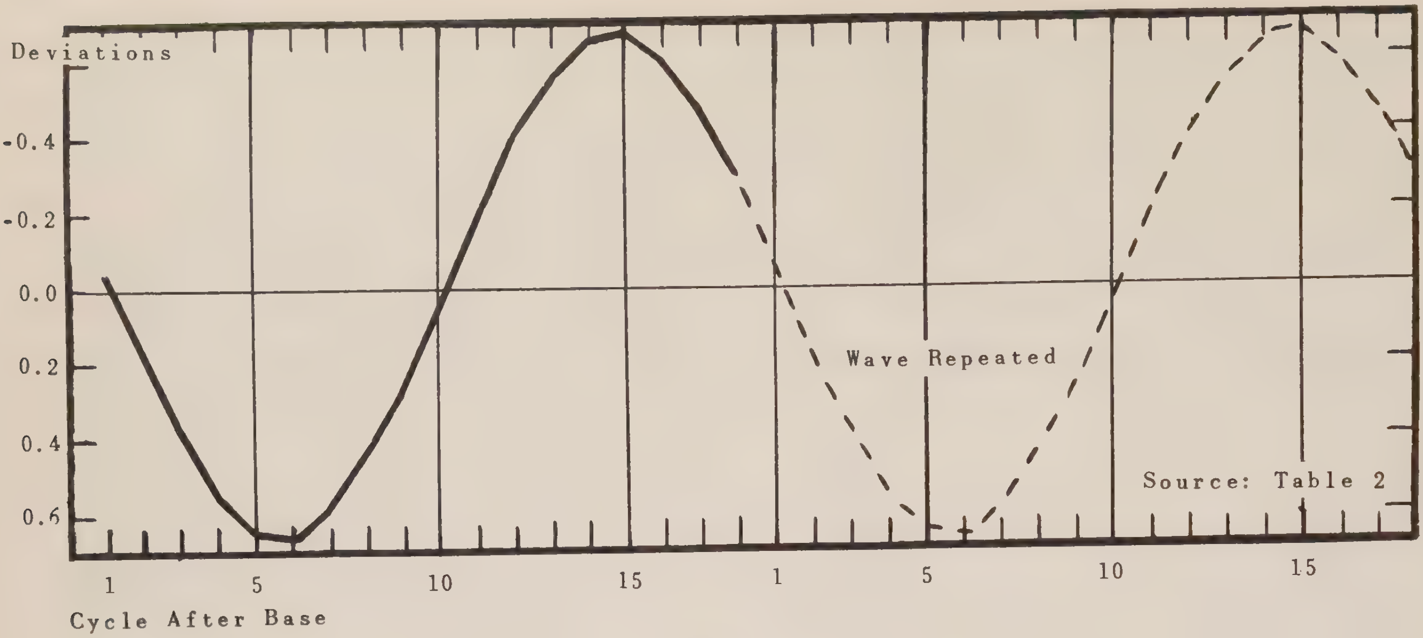


Fig. 6: The smoothed modified mean of the entire 18-item periodic table.

The values in Fig. 5-B smoothed by a 9-item moving average of a 2-item moving average of a 6-item moving average.

Note that the scale is inverted.

This curve also represents a 9-item moving average of a 2-item moving average of a 6-item moving average of a zigzag curve of the same timing with amplitude of ±1.58.

the moving averages it is easy to compute the shape and amplitude of the original 18-item cycle from the shape and strength of the moving average itself.

This has been done. We find the original undistorted shape to have been zigzag. The original amplitude would have been ± 1.58. The timing occurs with lowest (earliest) value three-quarters of the way from the 14th to the 15th position of the 18-item periodic table, that is, at position 14.75 to base -179 or 821, depending upon which numbering system you use. Similarly the highest (latest) value falls at position 5.75, and crossover points at 1.25 and 10.25 respectively. Remember that the scale is inverted and that we are talking about successive 11.1-year sunspot intervals—not about years.

A curve of a 9-item moving average of a 2-item moving average of a 6-item moving average of a cycle of the above character is also plotted in Fig. 6, but the two curves correspond so closely that they can scarcely be distinguished.

CALENDAR TIMING

It is not known whether the 18-item cycle varies in length with the sunspot cycle or not. Assuming, however, that it does, times of maximum lateness would be 1.48 years after the value of the 19-item moving average associated with the base of -112 and every 18 base numbers thereafter. Similarly, times of maximum earliness would come 1.48 years before the value of the 19-item moving average associated with the base of -12 (nine base numbers later) and every 18 base numbers thereafter. Times of no distortion would, of course, be midway between.

The value of 1.48 years given in the preceding paragraph is not a typographical error. The strength of 1.58 years is the absolute strength that prevails at position 5.75. The value of 1.48 years is the correct value for the 6th position, the nearest reality.

Assuming that the 18-item cycle does *not* vary in length with the sunspot cycle, and that it is a rigid unvarying 199½ years long, or thereabouts, the times of maximum lateness would come relative to the *average* calendar position of the 19-item moving average. This interval is 8.83 years after base. Dates for both assumption are shown in Table 3, which is at the top of the next page.

The accuracy indicated in the following table is, of course, specious, even assuming the positioning of the cycle to be correct. For one thing, base numbers do not advance by fractional years, but jump every tenth cycle by a whole number. The decimals are run out merely to show how the figures were obtained.

Table 3

DATES OF MAXIMUM LATENESS

Assuming a length for the "200-year" cycle that varies with the secular variation of the sunspot cycle				Assuming a fixed length for the "200-year" cycle			
A	B	C	D	A	B	C	D
Base Year	19-Item Moving Average Value	Plus 1.48	Year of Crest	Base Year	Fixed Lag	Plus 1.48	Year of Crest
-111.5	7.40	1.48	-102.6	-111.5	8.83	1.48	-101.19
88.5	8.83	1.48	98.81	88.5	8.83	1.48	98.81
288.5	10.04	1.48	300.02	288.5	8.83	1.48	298.81
487.5	11.10	1.48	500.08	487.5	8.83	1.48	497.81
687.5	11.43	1.48	700.41	687.5	8.83	1.48	697.81
887.5	8.67	1.48	897.65	887.5	8.83	1.48	897.81
1087.5	8.95	1.48	1097.93	1087.5	8.83	1.48	1097.81
1287.5	7.85	1.48	1296.83	1287.5	8.83	1.48	1297.81
1486.5	6.82	1.48	1494.80	1486.5	8.83	1.48	1496.81
1686.5	7.22	1.48	1695.20	1686.5	8.83	1.48	1696.81
1886.5	7.00e	1.48	1894.98	1886.5	8.83	1.48	1896.81

e - estimated

LENGTH

As said above, the length of the 200-year cycle in the length of the sunspot cycle seems to be exactly 18 sunspot cycles long. To get its length in years all we need to do is to multiply 18 by the average length of the sunspot cycle.

Remember that our periodic table is in terms of deviations from the 19-year moving average of the 7-item moving average, and that this moving average varies slightly from an absolute 11.1 years. To get the exact length let us position the first and second halves of the periodic table as follows:

Average distance after base at time of crest (maximum distortion late) is as follows: (from table of timing)

1st 5 18-item cycles	9.76 years
2nd 5 18-item cycles	7.90 years
Slippage in 5 18-item cycles	1.86 years
Slippage in 1 18-item cycle	.37 years

Length of the 18-item cycle is, therefore

$$(18 \times 11.1) - .37 = 199.8 - .37$$
$$= 199.4$$

If randoms have been completely eliminated, this length is correct within 1/50 of one sunspot cycle or .22 years. However, such complete elimination of randoms in a series so short is too much to hope for, and, therefore, the margin of error is probably somewhat larger. In any event the average length is very close to 199 or 200 years.

Length determined this way is not quite the same as the length obtained by multiplying the computed average length of the sunspot cycle, 11.094 years (Dewey, 1958) by 18. Length arrived at this latter way would be 199.69 years. The two lengths are in substantial agreement; however, the method I have used seems to me to be preferable.

CAUSE

The simplest explanation of the cause of the 200-year cycle in the length of the sunspot cycle is, of course, chance.

The assumption of chance as the cause of the 200-year cycle in the length of the sunspot cycle would be much easier to accept if we could convince ourselves that the ordinary 11.1-year sunspot cycle was timed merely by chance, like the timing of the eruptions of a geyser.

I am not completely convinced that this is not so and that the 11.1-year sunspot cycle itself is not of this nature. If this mechanism should ultimately prove to be the case, it would not be too hard for a 200-year variation in its length, of the degree of regularity observed, to occur by chance alone.

This is probably not the place to enter into the pros and cons of a dynamic versus a forced cause for the sunspot cycle *per se*. It is enough to say that the degree of regularity observed could not occur *easily* as a result of chance alone (Dewey, 1958).

If this latter assumption proves to be correct, it would be harder for a variation of the magnitude and regularity of the 200-year cycle to occur by chance alone. Both these facts being so, it behooves us to look for a possible causative factor.

Alternatively the cause could be another cyclic force 1/17 or 1/19 of 199.40 years. In other words a concurrent cycle 11.73 or 10.49 years long. A cycle of either of these lengths, properly combined with the 11.1-year sunspot cycle, might make the sunspot cycle come early at 199.4-year intervals, and, of course, come late about 100 years later.

A periodogram analysis of quarterly average sunspot numbers made by G. T. Lane (Lane, 1954) shows possible minor sunspot cycles of about 10.59 and 11.73 years in length respectively. The 10.59-year cycle is too far from our needs to be acceptable. (A difference of 1/10 year per cycle would put the 10.59-year cycle out of phase by 1.9 years in one 200-year cycle; 19 years out of phase by the end of 2,000 years. Such a discrepancy

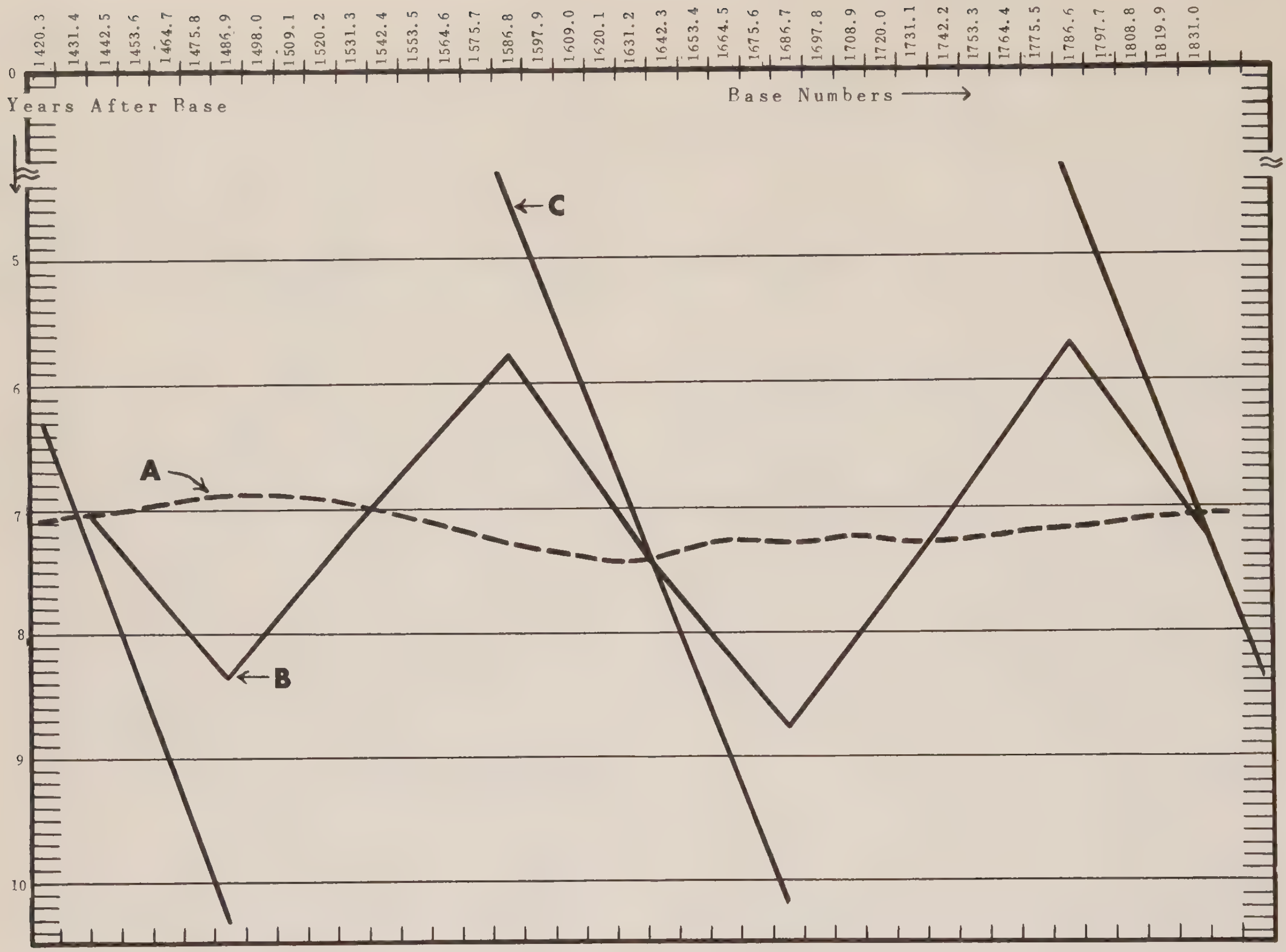


Fig. 7: A section of the 11.1-year time chart, enlarged and refined.

Curve A: The 19-item moving average of the 7-item moving average of the dates of sunspot maxima (refined basis). This curve gives normal secular timing of the maxima.

Curve B: The timing of the ideal 199½-year cycle (assuming that this cycle varies in time with the secular trend of sunspot maxima).

Curve C: The timing of the 11.73-year minor sunspot cycle, if real.

Note that the base numbers proceed evenly by 1/10 years instead of by integral years, rounded, as in Fig. 1, and that the grid is broken.

would, of course, never duplicate the observed behavior.)

A periodogram analysis does not, of itself, prove the existence of a rhythmic cycle. It does not even necessarily give us an exact determination of length. All it gives is a *hint* of a rhythmic cycle of the indicated length (Dewey, 1951). However, if a 11.73-year cycle is really present in sunspot numbers, 1749—1959, it can be *timed* by a periodic table of 11.73-year length. This timing has been computed (Murtha, 1960). If the cycle is present, crests are present, ideally, at 1849.75 and at 11.73 years or 11.75 years forward and backward from that date.

If we plot the maxima of the 11.73-year cycle onto a refinement of the 11.1-year time chart grid used to diagram the manifest 11.1-year cycle of sunspots, we achieve the results shown in Fig. 7. The grid is the same as the grid of Fig. 1, except that the base numbers are not rounded, but progress evenly by 11.1-year intervals. Values of .5 have been added to both base numbers and sunspot maxima to position them accurately within the year and to make them comparable with the timing of the 11.75-year cycle, which was so positioned. In Fig. 7, Curve A represents the 19-item moving average of the 7-item moving average of the time chart values. Curve B represents the timing of the ideal 200-year cycle. Curve C represents the timing of the 11.75-year cycle.

For an 11.73-year cycle to have the postulated effect both the 11.73-year cycle and the sunspot cycle would have to have the same secular variation in wave length. This, of course, might be the case. Gleissberg states that the minor sunspot cycles vary in length with the 80-year variation in length of the sunspot cycle (Gleissberg, 1958). It is conceivable that the postulated 11.73-year cycle varies on its part with the secular variation. There is no evidence one way or the other.

Fig. 7 may need a little further explanation. If we have an 11.1-year cycle and a 11.73-year cycle present concurrently in the same series of figures (e.g., something such as sunspots acted upon by two rhythmic forces of 11.1- and 11.73-year periods, respectively), when the two forces crest at the same time, there will be no distortion of the one (say the 11.1-year one) by the other. In other words, this event will occur at the *normal* timing of each.

Now by eliminating the 200-year wave (nine early cycles followed by nine late ones, on the average), the 19-item moving average (Fig. 7, Curve A) gives us the *theoretical* normal timing of sunspot maxima. That is, it gives us the approximate time that they would come if there were no 18-maxima (200-year) tendency to come first early, then late.

The zigzag line in Fig. 7 (Curve B) diagrams the ideal come early, come late, tendency. When Curve B is above Curve A, the maxima tend to come early (on the average); when Curve B is below Curve A, the maxima tend to come late. The higher above, the earlier; the lower below, the later. Midway between the crest and the trough of Curve B they both come on time—neither early nor late. In other words, this is the time when the maxima have normal timing. At this time the actual ideal normal timing coincides with the theoretical normal timing and Curve B cuts Curve A, either going up or coming down.

Now the interesting thing is that when we plot the timing of the maxima of the postulated 11.73-year cycle as determined from year by year figures, 1749—1957 (Curve C), it, too, falls just at this time. In other words, it coincides with the timing of the 11.1-year cycle just when that timing is normal—exactly as it would do if it were the causative factor of the distortion. That is to say, all three curves intersect at the same time.

Ahead of the times when all three curves are together, the 11.73-year cycle crests earlier than normal sunspot maxima timing. This fact might be responsible for pulling the sunspot maxima early. *After* the times when all three curves are together, the 11.73-year cycle crests later than normal sunspot maxima. This fact might be responsible for pulling the sunspot maxima late.

The fact that Curve C intersects Curve B just where Curve B crosses Curve A (as it should if the 11.73-year cycle is real and is the causative element of the 200-year cycle in the length of the sunspot cycle), may, of course, be pure coincidence. I could argue the case either way. However, coincidental or significant, one must admit that the behavior is dramatic.

DISCUSSION

The 200-year cycle in the length of the sunspot cycle (whether accidental or not) is a reality. Ideas of cause are pure speculation.

I do not advance the idea of a concurrent 11.73-year cycle as my idea of *the* cause of the 200-year variation in the length of the sunspot cycle. It is merely a conceivable cause. And the way in which the timing comes out just the way it should, if this happens to be the true explanation, is rather neat.

Let me advance the arguments against this explanation.

First, the existence of an 11.73-year cycle in sunspot numbers is not *proved.* All we have is periodogram evidence that something fairly close to this length is present on the average, either as an actuality or as an artifact.

There are even reasons for doubting its reality. It is not present equally in each half of the sunspot data, 1749—1959. And it comes at the "wrong" time based on a similar cycle found in the abundance of lynx, and the laws of latitudinal passage.

On the other hand, if it is a real cycle we do know its timing.

Second, for an 11.73-year cycle to distort an 11.1-year cycle to 1.58 years early and then to 1.58 years late involves assumptions regarding the way in which such a force would operate that may or may not be true.

Third, as stated above, for the effect to be as observed, the 11.73-year cycle would have to vary in length over the centuries in the same way in which the sunspot varies in length. There is, as of now, no way of knowing whether it does or does not.

On the other hand, the concurrent presence of an 11.73-year cycle is a *possible* explanation, and, assuming that it is the true explanation, the way in which the pieces fit together is quite dramatic.

The upshot of this study is, therefore; the 200-year cycle in the length of the sunspot cycle is real; its cause, as yet, purely conjectural.

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THE 11.73-YEAR CYCLE IN SUNSPOT NUMBERS

BY RUTH V. MURTHA

In connection with a study of the 200-year cycle in sunspot numbers (Dewey, 1960) it became necessary to definitize any possible 11.73-year cycle in sunspot numbers.

A periodogram analysis of sunspot numbers by G. T. Lane (Lane, 1954) suggests a cycle about 11.73 years in length in the quarterly averages of sunspot numbers, July, 1749—October, 1952. Note, however, that a periodogram analysis does not prove the existence of a cycle and does not even guarantee the correct length of a cycle that may truly be present (Dewey, 1951). The periodogram merely suggests the possibility of a cycle near the indicated length.

To determine the timing of the 11.73-year cycle in sunspot numbers, if there is one, as accurately as possible we have proceeded as follows:

As the dominant cycle in sunspot numbers over this period is, according to Lane's periodogram, 11.25 years, we placed the annual average sunspot numbers, 1749—1959, into an 11.25-year periodic table and averaged each column (Table 1).

We then adjusted the sunspot numbers for the average cycle thus obtained. Adjusted values exclude the 11.25-year cycle.

We then posted the adjusted values into a 11.75-year periodic table (the nearest length to 11.73 years possible with so short a series of annual figures). We averaged each column of the table and smoothed the results by a 4-year moving average of a 6-year moving average (Table 2 and Figure 1).

The smoothed averages crest at 7.25 years after base of 1842.5. This gives the date of a crest at 1849.75 with crest 11.75 or 11.73 years forward or backward from that date, providing, of course, that there is a cycle of this length inherent in these figures.

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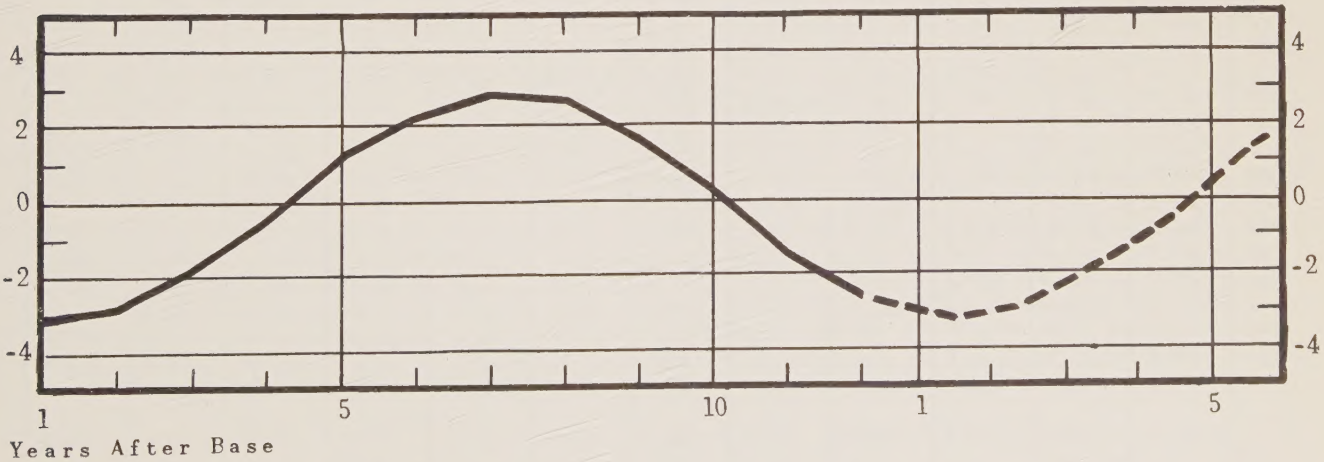

Fig. 1: The 11.75-Year Sunspot Cycle - Chart of a 4-year moving average of a 6-year moving average of the 11.75-year periodic table of annual sunspot numbers adjusted for the 11.25-year average cycle.

Table 1

11.25-Year Periodic Table of Relative Sunspot Numbers

Years After Base

Base Years	1	2	3	4	5	6	7	8	9	10	11	11.25
1748	80.9	83.4	47.7	47.8	30.7	12.2	9.6	10.2	32.4	47.6	54.0	
1759	62.9	85.9	61.2	45.1	36.4	20.9	11.4	37.8	69.8	106.1	100.8	81.6
1771	66.5	34.8	30.6	7.0	19.8	92.5	154.4	125.9	84.8	68.1	38.5	
1782	22.8	10.2	24.1	82.9	132.0	130.9	118.1	89.9	66.6	60.0	46.9	
1793	41.0	21.3	16.0	6.4	4.1	6.8	14.5	34.0	45.0	43.1	47.5	
1804	42.2	28.1	10.1	8.1	2.5	0.0	1.4	5.0	12.2	13.9	35.4	45.8
1816	41.1	30.4	23.9	15.7	6.6	4.0	1.8	8.5	16.6	36.3	49.7	
1827	62.5	67.0	71.0	47.8	27.5	8.5	13.2	56.9	121.5	138.3	103.2	
1838	85.8	63.2	36.8	24.2	10.7	15.0	40.1	61.5	98.5	124.3	95.9	
1849	66.5	64.5	54.2	39.0	20.6	6.7	4.3	22.8	54.8	93.8	95.7	77.2
1861	59.1	44.0	47.0	30.5	16.3	7.3	37.3	73.9	139.1	111.2	101.7	
1872	66.3	44.7	17.1	11.3	12.3	3.4	6.0	32.3	54.3	59.7	63.7	
1883	63.5	52.2	25.4	13.1	6.8	6.3	7.1	35.6	73.0	84.9	78.0	
1894	64.0	41.8	26.2	26.7	12.1	9.5	2.7	5.0	24.4	42.0	63.5	53.8
1906	62.0	48.5	43.9	18.6	5.7	3.6	1.4	9.6	47.4	55.4	103.9	
1917	80.6	63.6	38.7	24.7	14.7	5.8	16.7	44.3	63.9	69.0	77.8	
1928	65.0	35.7	21.2	11.1	5.7	8.7	36.1	79.7	114.4	109.6	88.8	
1939	67.8	47.5	30.6	16.3	9.6	33.1	92.1	155.8	136.2	136.4	83.3	68.9
1951	31.1	13.3	4.2	37.9	142.3	189.7	184.7	154.8				
Σ	1131.6	880.1	629.8	514.2	516.4	564.9	752.9	1043.5	1254.9	1399.7	1328.3	3273
Avg.	59.6	46.3	33.1	27.1	27.2	29.7	39.6	54.9	69.7	77.8	73.8	65.5

Table 2

11.75-Year Periodic Table of Relative Sunspot Numbers Adjusted for 11.25-Year Average Cycle

Years After Base

Base Years	1	2	3	4	5	6	7	8	9	10	11	11.75
1748	21.3	37.1	14.6	20.7	3.5	−17.5	−30.0	−44.7	−37.3	−30.2	−19.8	3.3
1760	39.6	28.1	18.0	9.2	−8.8	−28.2	−17.1	0.1	28.3	27.0	16.1	6.9
1772	−11.5	−2.5	−20.1	−7.4	62.8	114.8	71.0	15.1	−9.7	−35.3	−36.8	
1783	−36.1	−9.0	55.8	104.8	101.2	78.5	35.0	−3.1	−17.8	−26.9	−18.6	−25.0
1795	−17.1	−20.7	−23.1	−22.9	−25.1	−20.9	−24.7	−34.7	−26.3	−17.4	−18.2	−23.0
1807	−19.0	−24.7	−29.7	−38.2	−49.9	−57.5	−63.9	−38.4	−19.7	−18.5	−15.9	−9.2
1819	−11.4	−20.6	−25.7	−37.8	−46.4	−53.1	−41.5	−24.1	2.9	20.7	37.9	
1830	20.7	0.3	−21.2	−26.4	2.0	51.8	60.5	29.4	26.2	16.9	3.7	−2.9
1842	−16.5	−14.7	0.5	8.6	28.8	46.5	22.1	6.9	18.2	21.1	11.9	−6.6
1854	−23.0	−35.3	−32.1	−14.9	16.0	21.9	11.7	−0.5	−2.3	13.9	3.4	−10.9
1866	−22.4	−2.3	19.0	69.4	33.4	27.9	6.7	−1.6	−16.0	−15.8	−14.9	
1877	−26.3	−33.6	−22.6	−15.4	−18.1	−10.1	3.9	5.9	−7.7	−14.0	−20.4	−23.4
1889	−32.5	−19.3	3.3	7.1	4.2	4.4	−4.5	−6.9	−0.4	−15.1	−20.2	−36.9
1901	−49.9	−45.3	−35.8	−10.3	−11.7	2.4	2.2	10.8	−8.5	−21.5	−26.1	−38.2
1913	−45.3	−22.3	−22.4	30.1	21.0	17.3	5.6	−2.4	−12.5	−23.9	−22.9	
1924	−10.6	−5.8	−8.8	4.0	5.4	−10.6	−11.9	−16.0	−21.5	−21.0	−3.5	24.8
1936	44.7	31.8	15.0	8.2	1.2	−2.5	−10.8	−17.6	3.4	52.5	100.9	66.5
1948	58.6	9.5	3.4	−28.5	−33.0	−28.9	10.8	115.1	160.0	145.1	99.9	
Σ	−136.7	−149.3	−111.9	60.3	86.5	136.2	25.1	−6.7	59.3	57.6	56.5	−74.6
A	−7.6	−8.3	−6.2	3.3	4.8	8.1	1.4	−0.4	3.3	3.2	3.1	−5.7
B	−3.6	−3.3	−1.0	0.5	1.8	3.4	3.4	3.1	0.8	−0.7	−2.0	−3.6
C	−3.1	−2.9	−1.8	−0.5	+1.2	+2.3	2.9	2.7	1.7	0.3	−1.4	−2.5

A - Average
B - 6-year moving average
C - 4-year moving average of 6-year moving average

Mr. H. A. Musham
Naval Architect
741 Rush Street
Chicago 11, Illinois